



ACTA  
SILVATICA  
&  
LIGNARIA  
HUNGARICA

AN INTERNATIONAL JOURNAL  
IN FOREST, WOOD  
AND ENVIRONMENTAL  
SCIENCES

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# ACTA SILVATICA ET LIGNARIA HUNGARICA

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*Manuscripts and editorial correspondence should be addressed to*

TAMÁS HOFMANN, ASLH EDITORIAL OFFICE

UNIVERSITY OF WEST HUNGARY, Pf. 132, H-9401 SOPRON, HUNGARY

*Phone:* +36 99 518 311

*E-mail:* aslh@nyme.hu

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## Climate Change in Hungarian Rural Society: Assessment of Adaptive Capacity

Judit PAPPNÉ VANCÓS<sup>a\*</sup> – Mónika HOSCHEK<sup>b</sup> – Ferenc JANKÓ<sup>a</sup>

<sup>a</sup> Institute of International and Regional Economics, Faculty of Economics,  
University of West Hungary, Sopron, Hungary

<sup>b</sup> Institute of Economics and Methodology, Faculty of Economics,  
University of West Hungary, Sopron, Hungary

**Abstract** – Beside sustainable development, vulnerability might be the most frequently used expression in environmental studies. Vulnerability depends on the intensity of the impacts on a natural or social system as well as on its adaptive capacity. Appropriate adaptation warrants successful survival of the system even under high impact, when its vulnerability is significantly reduced; therefore, measuring adaptive capacity should have an established place in the methodology of impact – adaptation – vulnerability research. The main problem is to find relevant data that are required to establish indicators. In our study, the focus was laid on measuring adaptive capacity within vulnerability research, and on identifying possibilities for accurate calculation of adaptation. An attempt was made to determine the adaptive capacity to droughts in the micro-regions of Zala County. It could be established that the adaptive capacity of the population in the rural areas of Zala County to the expected increase in drought frequency is very low, which can be primarily explained by the lack of knowledge about adaptive agriculture.

**adaptive capacity / vulnerability / adaptation / drought / climate change**

**Kivonat** – A vidéki társadalom klímaváltozással szembeni alkalmazkodóképessége. A sérülékenység a fenntartható fejlődés mellett talán a legnépszerűbb fogalom a környezeti kutatásokban. A sérülékenység mértékét az adott ökológiai vagy társadalmi rendszert érő hatások erőssége és az alkalmazkodóképesség mértéke határozza meg. A megfelelő adaptáció még erős hatások mellett is lehetővé teszi egy rendszer sikeres fennmaradását, jelentősen mérsékelve a sérülékenységet, így a hatás – alkalmazkodás – sérülékenység összefüggésben értelmezett vizsgálatok módszertanában kiemelt jelentőséget kellene kapnia az alkalmazkodóképesség körütekintő becslésének. A mérések során felmerülő legfőbb probléma az indikátorok előállításához szükséges releváns adatok felkutatása. Tanulmányunkban a sérülékenység vizsgálatokon belül első sorban az alkalmazkodóképesség becslésének kérdéseit igyekeztünk körüljárni, feltérképezni azokat a lehetőségeket, amelyek az alkalmazkodás pontosabb számítását teszik lehetővé, majd kísérletet tettünk aszályal szembeni alkalmazkodóképesség meghatározására Zala megye kistérségeiben. A leglényegesebb következtetéseket összegezve kijelenthető, hogy Zala megyében az aszályosság várható növekedése mellett a rurális tereken élők alkalmazkodási kapacitása jelentéktelen, ami elsősorban az alkalmazkodó mezőgazdálkodással kapcsolatos ismeretek hiányával magyarázható.

**alkalmazkodási kapacitás / sérülékenység / alkalmazkodás / aszály / klímaváltozás**

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\* Corresponding author: vancsojudit@gmail.com; H-9400 SOPRON, Erzsébet u. 9. Hungary

## 1 INTRODUCTION

Measurement and estimation of societal adaptive capacity mostly belongs to the methodology of vulnerability research. Impacts, which enhance social vulnerability to outside stress, should be mapped and social preparedness for those negative effects must be assessed. Previous research showed that accurate measurement of adaptive capacity causes the greatest problem among the factors of vulnerability; quantitative methods are combined with qualitative techniques (e.g. Wilhelmi – Wilhite 2002, Adger – Wincent 2005; Brooks et al. 2005; Gupta et al. 2010). These questions earn great importance in the Hungarian literature as well (Pálvölgyi et al 2010, Pálvölgyi – Czira 2011, Pappné Vancsó et al 2014a, 2014b; Farkas 2015), so we put the focus of the study here on showing a methodological case study from a rural region in Hungary (Zala County). Nevertheless, it is important to introduce the context in which adaptive capacity is interpreted; thus, we also present how vulnerability has come into the focus of climate change research, and review the definition and methodological issues around vulnerability studies.

Vulnerability as a term has been known for a long time. It was first used in the medical and biological sciences; however, it has become an interdisciplinary concept, which has a crucial role in climate change and adaptive capacity research both from the side of natural and social sciences (see e.g. Vincent 2004, Smit – Wandel 2006; Kittel et al. 2011). Assessment of vulnerability and adaptive capacity research can be interpreted as responses given to the challenges of climate change, which started from the examination of local areas and reached the comparative analysis of national capacities. Local and regional-level analyses, however, have still remained very important as climate change affects certain areas in different ways and, therefore, the adaptive opportunities and capacities of local populations may also be different. Fortunately, research on regional level vulnerability not only appears in foreign professional literature, but similar studies have also been carried out in Hungary mainly in connection with the impacts of climate change on ecological and built environment (droughts, forest fires and urban heat waves, see Pálvölgyi et al. 2010, Pálvölgyi et al. 2011), and its complex impacts from the perspective of the environment (Farkas 2015).

Within the group of indices used for vulnerability calculation, indices for adaptive capacity are typically made of data, which are able to approach a particular problem indirectly, since information for large-scale examinations may be obtained almost exclusively from statistical databases. However, this does not present a problem in the case of indices used for impact-mapping because the indices of given possible outcomes of climate change (drought, heat wave frequency, excess water inundation) are already available (e.g. drought index) or they can be easily established (e.g. changes in the frequency of days with excess water inundation). However, given the lack of data which directly measure adaptive capacity, the results may become broad-brush.

Our research focuses on the elimination of this problem, and also on how to measure adaptive capacity accurately. Following the above mentioned domestic studies, we measured drought and flash flood vulnerability in micro-regions of Zala County, taking the concept of adaptive capacity into further consideration (Pappné Vancsó et al. 2014 a, 2014b). The local population will face two major problems concerning the proposed impacts of forecasted climate change delineated in mainstream national documents (Láng et al. 2007, NCCS 2008; NCCS 2013) and publications (e.g. Pongrácz et al. 2009; Sábitz et al. 2013), underlined as well as by the results of a questionnaire survey carried out in 2013, which examined the impacts of climate change on agricultural society. These are the increase in drought frequency as a result of decreasing amount of uneven precipitation and the gradually warming climate (1), and the more frequent flash floods, which can also be attributed to the uneven distribution of rainfall (2).

This paper does not provide a comprehensive picture of vulnerability, but it aims to highlight the problems of measuring adaptive capacity by the example of adaptive capacity to droughts.

## 2 THEORETICAL BACKGROUND

The term “vulnerability” was first placed into the focus of climate change research by Peter Timmerman (1981) under the influence of the major objectives of the World Meteorological Organisation (WMO) at that time. The WMO set it as a key research objective to determine those characteristics which made societies at different levels of development vulnerable or adaptive to fluctuations or changes in the climate. Timmermann’s definition – “vulnerability is the degree to which a system acts adversely to the occurrence of a hazardous event” (ibid. p. 21.) – has been transformed in several ways, which suggests that similarly to sustainable development and sustainability, vulnerability is a term that is subject to constant change and is difficult to define.

According to the working group of IPCC engaged in vulnerability research, from the perspective of climate change, a vulnerable system is sensitive even to slight changes in climate, and its adaptive capacity is seriously limited. In contrast, a flexible system or society is insensitive to fluctuations or changes in the climate, and is capable of adaptation (McCarthy et al 2001).

Similar to vulnerability, adaptation and adaptive capacity are diverse terms, which can be approached from several perspectives. Attempts have been made to formulate a general definition for adaptive capacity as well, according to Brooks, N. (2003) for instance, it is interpreted as “adjustments in a system's behaviour and characteristics that enhance its ability to cope with external stress”. Actually, the term can be interpreted from several perspectives, for example, from that of biology (e.g. Bock 1980), or forestry (Mátyás – Kramer 2016). Environmental adaptive capacity, which is closely related to our topic, may also be interpreted from the perspective of ecosystem and society. Adaptation depends on the natural systems, genetic and biological diversity, and the diversity of species. However, in social systems the existence of institutions and networks which preserve knowledge and experience support flexible problem-solving and restore the balance of power among different social groups (Berkes et al. 2002).

Naturally, different interpretations have been formulated to define adaptive capacity to climate change. Smit, B. et al (2000) describes adaptation as adjustments in ecological-socio-economic systems in response to actual or expected climatic stimuli, their effects or impacts. In another perspective, adaptations are interpreted as the adjustments in individual groups and institutional behaviour in order to reduce society’s vulnerability to climate change (Pielke 1998). According to the IPCC, adaptive capacity is defined as the ability of a natural or social system to adapt to climate change, to moderate potential damages, to take advantage of the opportunities, or to cope with the consequences (McCarthy et al 2001). The common feature of the different definitions is that they imagine adaptive society as a system which is capable of self-organisation and self-regulation, and is able to cope with the potential negative consequences of climate change.

## 3 MATERIALS AND METHODS

During our work, we took the methodology and certain findings of earlier Hungarian vulnerability research as a basis, which started from the correlations between impacts, adaptive capacity and vulnerability proposed by the IPCC. As a first step in applying the model, we identified those climatic problems (e.g. drought) which may make the affected systems, in our

case agricultural society, vulnerable. Secondly, we identified those impacts which stemmed from the exposure (e.g. exposure to drought) and sensitivity (e.g. soil sensitivity to drought) of the system, by taking the appropriate indicators into consideration. As a third step, we calculated adaptive capacity, and evaluated vulnerability based on the relationship between the impacts and adaptive capacity (Pappné Vancsó et al 2014 a, 2014b).

For the purposes of calculation, we took the parameters presented in *Table 1* into consideration, where we also included some other indicator groups used for vulnerability research as a comparison. In our study, the main objective was to make adaptive capacity calculations more accurate; therefore we would not delineate the comprehensive process of vulnerability calculations.

As can be seen in *Table 1*, vulnerability research focusing on the same problem may be very different in terms of perspective. Similarly, the different methods for calculating adaptive capacity are also varied. When establishing the indicators for measuring adaptive capacity of the rural population in Zala County, we started from the findings of a questionnaire survey and interviews which were conducted within the framework of a project acknowledged below. The aim of the questionnaire survey was to measure the respondents' perception of climate change, their knowledge of adaptation, and their established strategies and practices.

*Table 1. Indicators used for calculating drought sensitivity*

| Indicators used for measuring social vulnerability to drought<br>(Pappné et al 2014a.)         |                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                      |
|------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Impact                                                                                         |                                                                                                                                                                                                                                                                                    | Adaptation                                                                                                                                                                                                                                                                           |
| Exposure                                                                                       | Sensitivity                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                      |
| PaDI                                                                                           | - certain physical and water management features of the soils: field water capacity, wilting point, available water resource, infiltration rate, hydraulic conductivity, bedding of soil profile, features determining soil's special water management, water retention ability    | - level of knowledge relating to adaptive agriculture (e.g. technology and varietal conversion)<br>- availability of water for irrigation<br>- proportion of direct and indirect agricultural support per farming unit<br>- HDI<br>- Indicator calculated based on the figures above |
| Indicators used for measuring social vulnerability to drought<br>(Pálvölgyi et al. 2010; 2011) |                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                      |
| Impact                                                                                         |                                                                                                                                                                                                                                                                                    | Adaptation                                                                                                                                                                                                                                                                           |
| Exposure                                                                                       | Sensitivity                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                      |
| Pálfai Drought Index (PDI)                                                                     | - certain physical and water management features of the soils: field water capacity, wilting point, available water resource, infiltration rate and hydraulic conductivity, bedding of soil profile, features determining soil's special water management, water retention ability | - gross value added of agriculture per farmer<br>- agricultural subsidies per hectare                                                                                                                                                                                                |

Table 1 cont. Indicators used for calculating drought sensitivity

| Indicators used for measuring environmental, economic and social vulnerability<br>(Farkas et al. 2015)             |                                                                                        |                                                                                  |
|--------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Impact                                                                                                             |                                                                                        |                                                                                  |
| Exposure                                                                                                           | Sensitivity                                                                            | Adaptation                                                                       |
| Changes in the number of hot days (1980-2010)                                                                      | - proportion of people employed in agriculture                                         | - amount of income per one tax payer                                             |
| Changes in the average temperature (1980-2010)                                                                     | - proportion of income from small-scale agricultural production                        | - ratio of people with university degree within the population aged 25 or over   |
| Changes in the amount rainfall (1980-2010)                                                                         | - proportion of people employed in industry                                            | - number of scientific or engineering-technological enterprises per 1,000 people |
| Size of plot                                                                                                       | - number of people suffering from respiratory or circulatory diseases per 1,000 people |                                                                                  |
| Amount of water supplied                                                                                           | - number of patients taking GP consultation per 1,000 people                           |                                                                                  |
|                                                                                                                    | - ratio of people over 65 to total population                                          |                                                                                  |
| Indicators used for measuring vulnerability to droughts (Drought Vulnerability Index)<br>(Wilhelmi – Wilhite 2002) |                                                                                        |                                                                                  |
| Impact                                                                                                             |                                                                                        |                                                                                  |
| Exposure                                                                                                           | Sensitivity                                                                            | Adaptation                                                                       |
| agro-meteorological data: long-term precipitation                                                                  | - water retention ability of the soils                                                 | - availability of irrigation                                                     |
| Crop Moisture Index (CMI)                                                                                          |                                                                                        |                                                                                  |

Their knowledge about adaptive agriculture and about the need for changes in the existing agricultural practices formed the basis of the indicator, including the changes in crop structure, planting periods and planted varieties, the use of plastic tunnels against frosts, covering, hail protection nets against hail damage, more efficient spraying, collecting rainfall, planting cover crops instead of ploughing that leads to soil dehydration and constructing draining systems. Increasing the proportion of forests and establishing water reservoirs for the purposes of irrigation. These factors were indicated in proportion to all the respondents (*Table 2*), interpreting it as 100% when each respondent was aware of and used the particular solution. When calculating the indicator for adaptive capacity, this component was taken into account as a factor weighting 60%.

A significant proportion of the respondents mentioned irrigation as an adaptive solution; therefore, we also took irrigation into account in the micro-regions subject of the research (proportion of surface water to the size of lands not irrigated) as a factor weighting 20%. However, seeing that irrigation may become an issue, and water sources suitable for irrigation may be scarcer in the future (NDS, 2014), this indicator should be taken into account with due care in our case. Prevention would be the appropriate solution in the adaptation process, increasing the water retention capacity of the soil, reducing evaporation by using modern agro-technological equipment and growing plant species with abilities to adapt to uneven precipitation.

Therefore, irrigation offers a less efficient solution for adaptation to droughts compared to the other possibilities mentioned above; however in Zala County, such opportunities are far from being exploited: based on the data provided by WTWD (2014) only 0.2% of the total arable land belongs to that category. Therefore, it can be presumed that there would be

remaining reserves even in the case of increasing droughts. Seeing that irrigation is basically connected to surface waters, we considered the ratio of available surface waters (water courses, channels and standing waters) to the size of arable lands not irrigated in the particular micro-region when calculating the indicator. We used the CORINE land cover data included in the NISRD (TEIR) database. For instance, the 2.1 value of region Nagykanizsa means the proportion of the extent of surface waters to the total area used as not irrigated arable land in the micro-region. Naturally, the indicator is not perfect as the geographical extent of surface waters may not determine their actual water content; however, it illustrates well the availability of and limited access to surface waters. Irrigation, therefore, may be a necessary solution in certain cases, which cannot be ignored when calculating adaptive capacity, thus it was taken into account as a factor weighting 20%.

For adaptive capacity calculations, another 5-5% was assigned for three indicators relating to farmers' ability in applying for tenders. Aptitude and resilience may also be very important factors of adaptation, which were expressed in the successful applications of farmers living in the micro-regions for agricultural support. It can be reasonably assumed that micro-regions which are able to apply for tenders efficiently are more capable than their less successful counterparts. Regions where the proportion of support other than direct area-based payment is higher are presumed to be more capable since obtaining indirect subsidies and the application process pose great challenges due to the difficulties of application. It is also a significant indication, whether there are differences in the amount of funds received per farmer because a wealthier farmer may also be more successful in forced adaptation. In the case of the three indicators, we always regarded the best performing regions as 100%, and compared the performance of the other regions to that percentage. The data required to establish the three indicators were obtained from the public-interest database of the Agricultural and Rural Development Agency (ARDA 2014).

Adaptation also depends on human factors including knowledge and preparedness; therefore, when formulating our index, we also took the Human Development Index (HDI) into consideration. HDI is an aggregate index, with the components of life expectancy at birth, years of schooling, and gross national income per capita. Considering the fact that the latter component cannot be constructed on the regional level, we substituted it by income per capita. In our calculations, HDI was evaluated between 0 and 100, and similar to agricultural support, the micro-region with the best HDI index was regarded as 100%. Similar to the last three indicators, this one was also taken into account as a factor weighting 5% for the calculation of adaptive capacity. The data relating to life expectancy at birth and the years of schooling were provided by the Hungarian Central Statistical Office (HCSO 2011) broken down by micro-region. The data relating to income per capita broken down by settlement were retrieved from the NISRD database.

#### **4 RESULTS AND DISCUSSION**

Based on the results of the questionnaire survey, it can be generally established that nearly 90 percent of the respondents perceived the signs of climate change. It was reflected by the occurrence of dry summers, uneven precipitation and the changes in the normal pattern of the seasons. It was generally stated that such changes had negative impacts on agriculture. Only 30 percent of the respondents claimed that they would be able to adapt to the consequences of climate change in some way. They saw that the success of adaptation laid in environmentally-conscious lifestyle (approximately 20%), irrigation (nearly 60%), and the changes in existing agricultural practices i.e. adaptive agriculture (17%). As highlighted above, the latter would offer a more efficient solution than irrigation in the battle against drought; relatedly, that is why

we weighted the “level of knowledge relating to adaptive agriculture (technology and varietal conversion)” as the most important indicator representing the adaptive capacity of the society. Seeing that in this respect we observed no significant differences among the micro-regions, the results were also similar in every case. Obviously, the efficiency of comparative analyses carried out on micro-regional level within a single county may be challenged even at that point, especially in the case of Zala County, where there are no significant differences in terms of natural conditions or land-use. It is more likely to obtain mathematically interpretable results from research addressing the whole country.

Table 2 shows that the access to surface waters is severely limited. The regions of Lake Balaton and Kis-Balaton would be exceptions, but we did not take their whole water surface into consideration because their access and availability is low relative to the proportion of their water surface, and Balaton is not surrounded by arable lands but areas for holiday purposes, and Kis-Balaton is a nature protection area. In the future, in the case of increased needs for irrigation, the availability of surface waters may be improved by constructing irrigation channels, water reservoirs among the hills and down-hole wells; however, such infrastructural investments and water use would incur additional expenses for agriculture.

Table 2. Calculation of adaptive capacity in the micro-regions of County Zala

|                                                                                                           | Micro-region |             |             |            |             |             |              |             |               |
|-----------------------------------------------------------------------------------------------------------|--------------|-------------|-------------|------------|-------------|-------------|--------------|-------------|---------------|
|                                                                                                           | Hévíz        | Keszthely   | Lenti       | Letenye    | Nagykanizsa | Pacsá       | Zalaegerszeg | Zalakaros   | Zalaszentgrót |
| Level of adaptive agriculture (variety and technology conversion %)                                       | 17.0         | 17.0        | 17.0        | 17.0       | 17.0        | 17.0        | 17.0         | 17.0        | 17.0          |
| Ratio of surface waters to size of arable lands not irrigated (%)                                         | 1.2          | 5.0         | 0.2         | 0.9        | 2.1         | 5.0         | 0.5          | 5.0         | 0.3           |
| Proportion of tender amounts won per farmer in relation to the best-performing micro-region (%)           | 23.0         | 58.0        | 72.0        | 38.0       | 50.0        | 100.0       | 49.0         | 41.0        | 56.0          |
| Ratio of tender-winning farmers from all the farmers in relation to the best-performing micro-regions (%) | 58.0         | 77.0        | 100.0       | 42.0       | 51.0        | 60.0        | 70.0         | 59.0        | 67.0          |
| Ratio of indirect support from all the support won in relation to the best-performing micro-regions (%)   | 68.0         | 74.0        | 100.0       | 58.0       | 84.0        | 67.0        | 77.0         | 69.0        | 64.0          |
| HDI in relation to the best-performing micro-regions (%)                                                  | 93.66        | 94.10       | 79.53       | 45.58      | 91.64       | 47.24       | 100.0        | 35.62       | 57.74         |
| Adaptive capacity (%)                                                                                     | <b>12.0</b>  | <b>16.0</b> | <b>18.0</b> | <b>9.0</b> | <b>14.0</b> | <b>15.0</b> | <b>15.0</b>  | <b>11.0</b> | <b>12.0</b>   |

Source: data calculated based on data by WTWD 2014, NISRDP 2014, ARDA 2014, HCSO 2011 and own questionnaire survey data.

In the case of indices related to tender applications, it is very difficult to assess the success or failure of certain micro-regions. The number of tender applications per farmer is very low: the county average is 23 percent, which means that only 23 percent of all registered farmers receive some agricultural support. This, however, can be explained by the high rate of small-scale farmers rather than by their failure (there are nearly 20,000 registered farmers in Zala County). The distribution around the average is insignificant: the micro-region of Nagykanizsa has the lowest (18%) and Lenti has the highest (35%) figures.

The tender amounts won per farmer (HUF 540,000 in county average) represent more significant differences between the micro-regions even if not on a large scale. Accordingly, the micro-region of Pacsa was in the most advantageous (HUF 1,000,000) while that of Hévíz in the least successful (HUF 230,000) position.

The ratio of direct area payments to indirect agricultural support was 48-52 percent on the county level in favour of indirect supports. The distribution of the amounts won is similar between the two tender types. It was typical of the majority of the micro-regions that the proportion of direct area payments exceeded that of indirect support with the exception of the micro-regions of Zalaegerszeg (50.7%), Nagykanizsa (56%) and Lenti (66%) where the ratio of direct area payments exceeded 50 percent; therefore, in this regard these three micro-regions are considered to have the highest performance.

Although there are differences among the three micro-regions, such differences are insignificant, and they do not modify the extent of adaptation, but only modulate it. Due to land fragmentation and the significant number of land owner farmers who possibly do not apply for tenders at all, it is very difficult to assess their success in tender applications.

The HDI values of the micro-regions in Zala County are between 24 (Zalakaros) and 64 (Keszthely), the average value of the nine micro-regions is 48, which significantly falls behind the ideal maximum values. Based on the index it cannot, therefore, be established that people in the county have good or exceptional socio-economic conditions. The general conditions of the society may also influence its adaptive capacity. It is arguable whether qualification or income position have an impact on adaptive capacity; however, poor health or low life expectancy at birth may contribute to it.

As it can be seen in the table above, based on the parameters examined there are no significant differences among the micro-regions in terms of adaptive capacity. The main reason is that local knowledge, which is required for adaptation about technology and varietal conversion, is typically not significant in the county as a whole. Having regard to the other indicators, no significant differences can be observed either between the micro-regions, which would essentially affect the findings. The micro-regions are prepared for the increasing needs for irrigation since agricultural irrigation has no traditions in the area. Based on the HDI, which indicates the level of schooling, income position and health condition, the social conditions of people living in the agricultural area of Zala County is about average, but far from being ideal.

Micro-regional level research focusing on one county if compared to the best performing research area, are not sufficient due to the limited comparability. Although databases are linked mostly to administrative boundaries, it would be more useful to connect climate change adaptation research to boundaries of geographical or agricultural regions, because perception of drought and its problems seems more relevant in case of cultural landscapes than on the micro-regional level.

In comparison with previous research (Wilhelmi – Wilhite 2002, Pálvölgyi et al. 2010, 2011, Farkas et al. 2015), we attempted to review the issue of adaptation, and in this regard we found it essential and important to ask for the opinion of the concerned people. Another difference was that in consultation with the relevant water authority, we obtained detailed information about the current utilisation of irrigation, and we also gained access to an individual database for the establishment of the micro-regional level HDI index. Previous research

attempted to measure adaptive capacity based on indirect data, focused mainly on economic indicators, and referred to factors such as schooling or financial position (Wilhelmi – Wilhite 2002, Brooks et al. 2005; Smit, B. – Wandel, J. 2006; Pálvölgyi et al. 2010, 2011, Farkas et al. 2015). Even though these characteristics are naturally important for adaptation, neither of them can specifically suggest whether the local population is or would actually be able to adapt to climate change. Comprehensive and reproducible studies require data that are also available to everyone over time; such studies, however, cannot be used to directly measure adaptive capacity. The rural population's knowledge about droughts and climate change in general, and about adaptation seen as responses to such challenges can only be measured accurately if we directly ask the opinion of the people concerned by means of detailed field work. Conducting field questionnaire surveys and interviews is time-consuming and their results may not be reproduced easily year by year; their main advantage, however, is that their findings are more specific compared to other studies which use available data exclusively; also, significant information will not get lost.

## 5 CONCLUSION

The study of societies' vulnerability to climate change has been brought into the focus of scientific research in the last few years. Similar to the diverse impacts of climate change, vulnerability studies are also diverse. However, the common feature of all such studies is that they examine the extent of vulnerability in relation to impacts and adaptive capacity in every case. Adaptive capacity has an essential role in dealing with the impacts. Nevertheless, the common ground of studies to date is for the means used for measuring adaptive capacities. They mostly used indirect indices which could be established on the basis of data retrieved from electronic databases with easy access, relating to the economic and social relations of the particular society, and presuming that societies with good conditions can adapt better to the challenges posed by climate change. In our research, we examined how the method of measuring adaptive capacity could be made more precise, and how to introduce new indicators in addition to the existing ones which are based on the opinion, experiences, and established adaptation practices of the society concerned. We found that if we want to learn about a society's knowledge about actual adaptation, direct questioning of the people concerned and detailed field work are essential. Indirect data relating to a society's health conditions, economic situation and qualification may be necessary components of the adaptation indicator; however, the most important index of the indicator must relate to adaptation practices. The drawbacks of questionnaire surveys and field work is that they are very difficult to reproduce with the lapse of time. Nonetheless, their main advantage is that they contribute more specific results to the adaptation index than indirect data, which, therefore, significantly increases the usability of the findings of vulnerability research and their occasional application in adaptation policies.

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## Sudden *Phytophthora* Dieback of Wild Cherry Trees in Northwest Hungary

Judit SÁRÁNDI-KOVÁCS<sup>a\*</sup> – László NAGY<sup>b</sup> – Ferenc LAKATOS<sup>a</sup> – György SIPOS<sup>a,c</sup>

<sup>a</sup> Institute of Silviculture and Forest Protection, Faculty of Forestry, University of West-Hungary, Sopron, Hungary

<sup>b</sup> Szombathely Forestry Corporation, Sárvár Forestry Directorate, Sárvár, Hungary

<sup>c</sup> WSL, Swiss Federal Research Institute, Birmensdorf, Switzerland

**Abstract** – During a regular survey of declining forests in 2011, sudden dieback symptoms were observed on scattered wild cherry trees (*Prunus avium*) in a mixed deciduous forest stand, located in the flood plain area of the Rába River, in northwest Hungary. In this study, we correlated both soil conditions and presence of *Phytophthora* spp. to dieback of cherry trees. Two *Phytophthora* species, *P. polonica* and *P. plurivora*, were isolated from the rhizosphere soil of the dying trees. By contrast, only *P. polonica* was recovered from the necrotic tissues of symptomatic roots. Stem and root inoculation tests on cherry seedlings showed pathogenicity of both species, although *P. polonica* proved to be more virulent. This is the first report of natural infections of *P. polonica*.

**soilborne pathogens / forest protection / *Phytophthora polonica* / *Phytophthora plurivora***

**Kivonat** – Madárcseresznye fák fitoftórási pusztulása Északnyugat-Magyarországon. Egy 2011-ben, pusztuló erdőállományokban végzett egészségi állapot-felmérés során egy elegyes erdőállományban a madárcseresznye fák pusztulására figyeltek fel a szerzők. Az erdőállomány a Rába folyó egy holtága mentén terül el. Egy két éves esettanulmány során, talajvizsgálatot és a talaj és a talált *Phytophthora* fajok hatását vizsgáló patogenitás-teszteket végeztünk. Eredményeinket statisztikailag értékeltük. Míg az erdőállomány talajából *Phytophthora plurivora*-t és *Phytophthora polonica*-t tenyésztettünk ki, a pusztuló fák tüneteket mutató gyökereiből csak *P. polonica*-t sikerült izolálni. Madárcseresznye-csemetéken elvégzett törzssebzési és gyökérfertőző kísérletek egyaránt kimutatták mindkét izolált faj patogenitását. agresszivitását statisztikai elemzések bizonyítják. Ez az első olyan alkalom, amikor természetes körülmények között a *P. polonica* kórokozónak bizonyult.

**talajlakó kórokozó / erdővédelem / *Phytophthora polonica* / *Phytophthora plurivora***

### 1 INTRODUCTION

Wild cherry (*Prunus avium* L.) is present in Hungarian mixed deciduous forests as scattered trees. Besides fungal and bacterial pathogens, several *Phytophthora* species are known to cause dieback of cherry trees under natural or experimental conditions (Santini et al. 2006, Kurbetli 2014, Vettraino et al. 2008). Among *Phytophthora* species, *P. alni* Brasier & S. A. Kirk, *P. cactorum* (Lebert & Cohn) J. Schröt., *P. cambivora* (Petri) Buisman, *P. cinnamomi* Rands, *P. citricola* Sawada, *P. citrophthora* (R. E. Sm. & E. H. Sm.) Leonian, *P. cryptogea*

\* Corresponding author: sarandi-kovacs.judit@emk.nyme.hu; H-9400 SOPRON, Bajcsy-Zs. u. 4. Hungary

Pethybr. & Laff., *P. drechsleri* Tucker, *P. megasperma* Drechsler, *P. nicotianae* Breda de Hahn and *P. syringae* (Kleb.) Kleb. are known to cause dieback of cherry trees under natural or experimental conditions (Mircetich – Matheron 1976, Thomidis – Sotiropoulos 2003, Santini et al. 2006, Thomidis et al. 2008, Vettrano et al. 2008). In this paper we describe the sudden death of wild cherry trees in northwest Hungary and evaluate the role of the combined impact of soil texture and soilborne *Phytophthora* spp. in the etiology of the disease.

## 2 MATERIALS AND METHODS

### 2.1 Isolation

In spring 2012 sudden dieback of twelve-year-old wild cherry trees was surveyed in a 1.84 ha mixed deciduous forest stand (pedunculate oak: 60%, common ash: 25%, wild cherry: 5%, eastern black walnut: 5%, other broadleaved tree species: 5%) partly surrounded by a backwater of the Rába River, near Sárvár (150 m above sea level) in northwest Hungary. Six symptomatic trees were randomly selected and necrotic root and rhizosphere soil samples were collected in a total amount of 500 g/sample. Both sample types were processed as previously described (Szabó et al. 2013). To recover *Phytophthora* isolates from the soil samples, cherry laurel (*Prunus laurocerasus* L.) and *Rhododendron* sp. leaves were used as baits. The infected leaf segments were placed onto selective PARPNH media (Jung et al. 2000). Morphological characterization was carried out as described by Szabó et al. (2013). All of the collected isolates were examined. For molecular identification, pure mycelial cultures were used for direct PCR with the PHIRE Plant Direct PCR Kit (Thermo Scientific) according to the manufacturer's user's guide. The ITS1-5.8S-ITS2 regions of the rDNA of selected isolates were amplified using the ITS6 and ITS4 primer pair (Cooke – Duncan 1997) in an Eppendorf Mastercycler Personal PCR machine. PCR conditions were as follows: 5 min initial denaturation at 98 °C, 5 s denaturation at 98 °C, 5 s annealing at 55 °C, 20 s extension at 72 °C (1 min for the final cycle) with 39 cycles in total. The amplified DNA fragments were sequenced in both directions in the Eurofin Laboratory (Ebersberg, Germany). All of the six collected isolates were sequenced and their sequence homologues were identified using Blast searches against the NCBI GenBank database (<http://blast.ncbi.nlm.nih.gov/Blast.cgi>). Accession numbers: KT693123; KT693124; KT693125; KT693126; KT693127; KT693128).

### 2.2 Pathogenicity tests

Pathogenicity tests were performed using two different soil conditions to compare the effect of the local sandy alluvial soil versus the control soil type typical of the forests of the region. Both soil types proved to be free of *Phytophthora* species prior to infestation according to the result of leaf baiting controls. Soil analyses were performed in the WSL soil laboratory (Swiss Federal Research Institute, Birmensdorf, Switzerland). The pathogenicity of one *P. plurivora* (Jung – Burgess 2009) and one *P. polonica* (Belbahri – Moralejo – Lefort 2011) isolate (both 14 days old, grown on 39g/l PDA at 20°C in the dark) was assessed in both soil types (sandy alluvial and control soils). Stem inoculation and root infection tests were carried out on two-year-old, container-grown wild cherry seedlings, using 10 replicates per *Phytophthora* species and 10 replicates as control (not infected). For root infection, four equal aliquots of mycelial culture were put into the planting medium in four directions around the stem of the seedlings (altogether two cultures/seedling). Stems were wounded inoculated by inserting an infested PDA plug (5-mm in diameter) under the bark using a sterile scalpel. Control seedlings were inoculated with sterile PDA. Wounds were sealed with Parafilm (Pechiney, Chicago, IL). Seedlings were maintained under outdoor natural conditions and were watered when

necessary. Lesion sizes were measured and the health condition of the shoots and roots was evaluated based on a five-point scale 13 weeks after inoculation (see *Table 1*). Necrotic tissues from the stem and roots of infected seedlings, and soil samples from the container of infected seedlings were collected for the re-isolation of *Phytophthora* species in order to fulfill Koch's postulates.

### 2.3 Statistical analyses

Statistical analyses were performed with STATISTICA 12 software (StatSoft, Inc. [2014]). Kruskal-Wallis and Mann-Whitney U tests were used for the comparison of the treatment groups. The effects of the two contributing factors (pathogen versus soil type) were evaluated both separately and together. Pearson Chi-square tests were performed to evaluate whether there is a significant correlation between treatments applied and the parameters of the root system. Boxplots were created and edited using SPSS (IBM, v. 22).

*Table 1: The five-point scale used for the evaluation of pathogenicity tests*

| Stage | Crown symptom                                | Root symptom                                                    |
|-------|----------------------------------------------|-----------------------------------------------------------------|
| 1     | Asymptomatic sapling                         | Healthy root system with plentiful healthy fine roots           |
| 2     | Smaller leaves with yellowish discolouration | Dead root tips and fine roots occurring locally (less than 30%) |
| 3     | 30%–50% of the crown is dead                 | 30%–50% of the root system is already dead                      |
| 4     | More than 50% of the crown is dead           | More than 50% of the root system is already dead                |
| 5     | Completely dead sapling                      | Completely dead sapling                                         |

## 3 RESULTS

### 3.1 Isolation and identification

Sudden dieback of young wild cherry trees was clearly observed in a forest stand at the inundation area of the Rába River at the time of budburst in spring 2012. Approximately 70% of the wild cherry trees showed severe wilting symptoms or were already dead. Bark cracking and stripping, gummosis and wood discoloration under necrotic bark on the lower stems and also necroses on the main roots were observed. Six *Phytophthora* isolates were obtained from five from of the six soil samples using leaf baiting and a single isolate from the necrotic tissues. Based on the comparison of morphological traits and homology (99–100%) to other ITS sequences, four *P. polonica* (three from the soil and one from necrotic tissues) and two *P. plurivora* isolates (both from the soil) were identified. The isolates of the two species could be easily distinguished based on the daily growth rate, the shape and amount of sporangia produced and the presence or absence of hyphal swellings. While the two *P. plurivora* isolates had a daily growth rate 6.50–6.83 mm, *P. polonica* colonies grew more slowly (4.50–4.67 mm/day). The colonies of *P. plurivora* isolates formed readily and abundantly sporangia with variable shapes but hyphal swellings were absent. In contrast, *P. polonica* isolates produced abundantly single or catenulate hyphal swellings either with globose or irregular shapes and only two isolates formed a few, ovoid, non-papillate sporangia.

The analysis of the soil types illustrated that the base saturation values were nearly identical and only soil textures were different (Table 2).

Table 2: Soil types used for the pathogenicity tests

|                     |                             | Sárvár     | Control soil |
|---------------------|-----------------------------|------------|--------------|
| Texture             | (% sand, silt, clay)        | 61, 24, 15 | 12, 54, 34   |
| pH                  | (0.02 M CaCl <sub>2</sub> ) | 5.06       | 7.35         |
| Ca <sub>exch</sub>  | (mg kg <sup>-1</sup> )      | 3819.39    | 6983.97      |
| Mg <sub>exch</sub>  | (mg kg <sup>-1</sup> )      | 604.76     | 700.45       |
| K <sub>exch</sub>   | (mg kg <sup>-1</sup> )      | 269.37     | 431.95       |
| Na <sub>exch</sub>  | (mg kg <sup>-1</sup> )      | < 5.20     | 14.83        |
| Mn <sub>exch</sub>  | (mg kg <sup>-1</sup> )      | 67.81      | 6.95         |
| Fe <sub>exch</sub>  | (mg kg <sup>-1</sup> )      | 2.75       | < 1.60       |
| Zn <sub>exch</sub>  | (mg kg <sup>-1</sup> )      | 1.27       | < 1.20       |
| Al <sub>exch</sub>  | (mg kg <sup>-1</sup> )      | 3.52       | < 2.00       |
| CEC                 | (mmol <sub>c</sub> /kg)     | 125.13     | 209.03       |
| Base saturation (%) |                             | 98.80      | 99.94        |

### 3.2 Pathogenicity tests

In the case of the uninfected seedlings, the root system remained healthy and rich in fine roots. In contrast, altogether six *P. polonica*-, and four *P. plurivora*-infested seedlings died during the thirteen weeks of the root infection experiment. Thinned root system, dead fine roots and root tips, and extremely short main roots were observed (Figure 1). Significant differences in the health conditions of roots ( $p = 0.000$ ) and in the root widths ( $p = 0.000$ ) were identified according to the results of the Kruskal-Wallis tests. For the roots' health conditions (Figure 2A), both the effect of soil type ( $p = 0.015$ ) and the pathogen ( $p = 0.000$ ) were significant according to the results of the Kruskal-Wallis tests. There was a significant correlation between the applied treatment and the health condition of the root system ( $p = 0.00000$ ) according to the Pearson Chi-square test. Although, there wasn't any significant correlation between the applied treatment and the root width based on the Pearson Chi-square test. *P. polonica* seemed to be slightly more aggressive than *P. plurivora*. Both *Phytophthora* species were re-isolated from symptomatic roots and from the infected growth media.

In the stem inoculation experiment, sunken and dark necrotic lesions developed at the inoculation points of infected seedlings while only callus formation was observed on the control stems. Significant differences in the health conditions of shoots ( $p = 0.002$ ) and necrotic areas ( $p = 0.001$ ) were found between the treatment groups according to the results of the Kruskal-Wallis tests. For shoot health conditions (Figure 2B), only the effect of soil type was significant ( $p = 0.000$ ) and the soil type did not have a significant impact on the size of the necrosis on the stems (Figure 2C). There was no significant difference in the aggressivity of the two species. Both *Phytophthora* species were re-isolated from the border of the lesions.

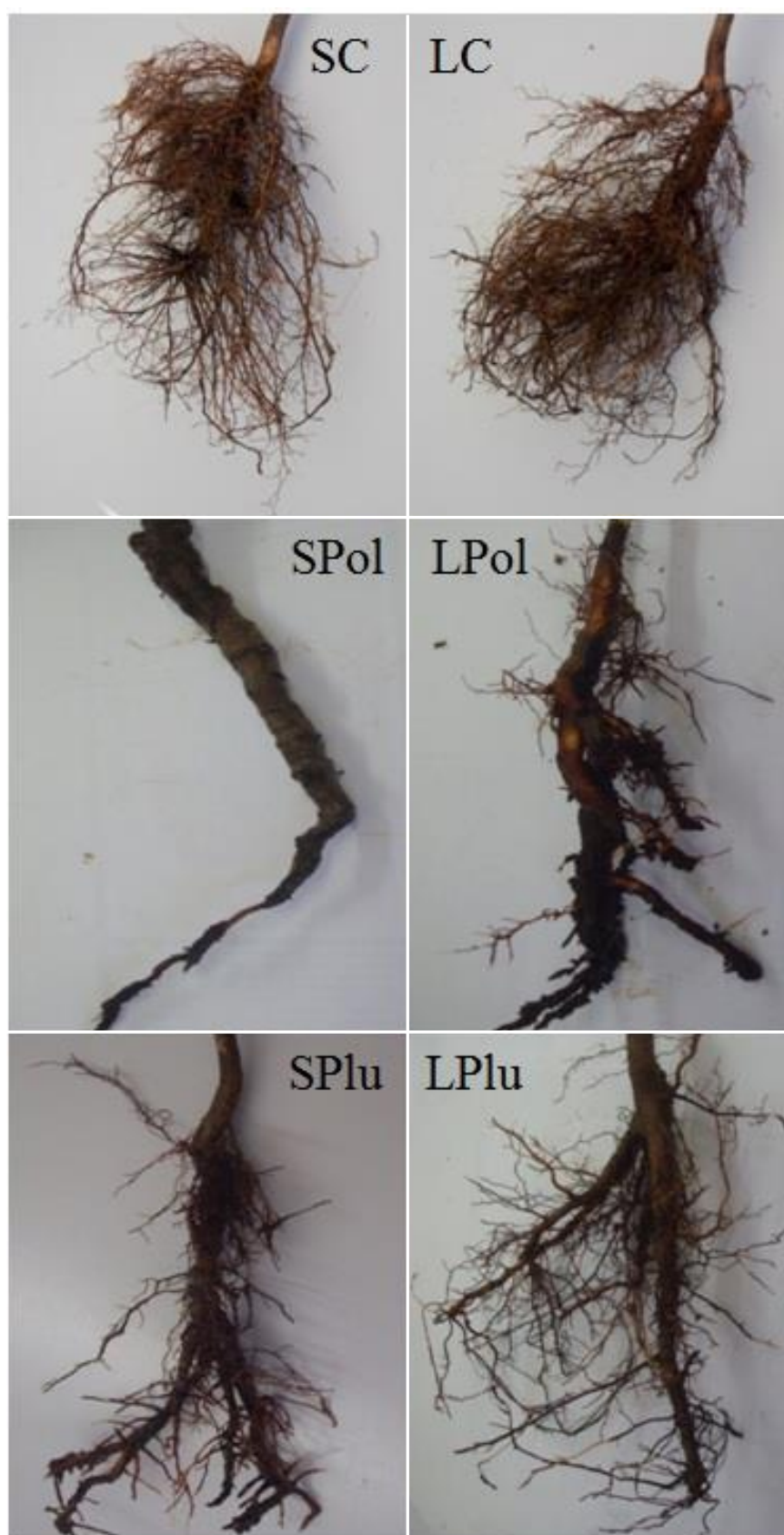


Figure 1. Root development in soil infection test  
(Abbreviations: L: control soil type, S: local alluvial soil type,  
Pol: *P. polonica*, Plu: *P. plurivora*, C: non-infected control)

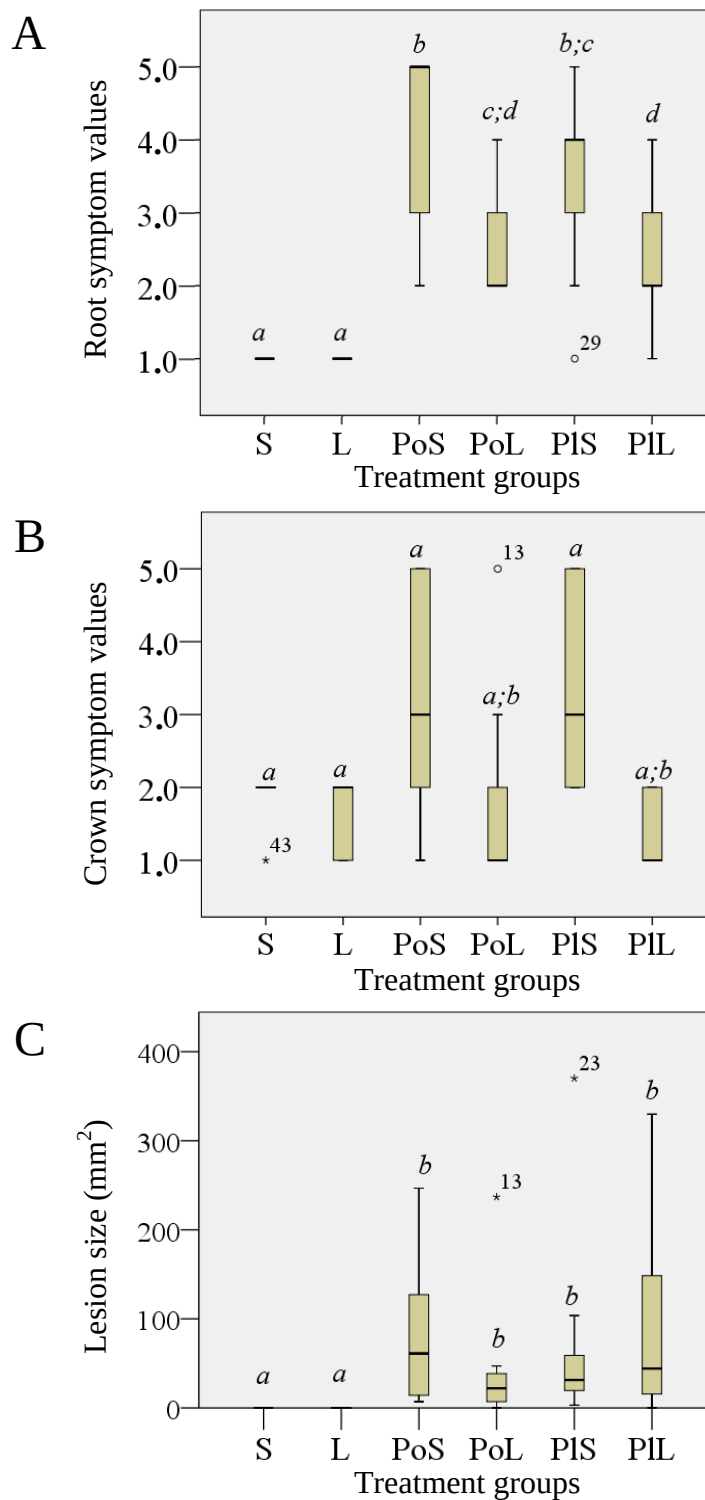


Figure 2.

- A: Root system health conditions in the different treatment groups (mean values; different labels mean significantly different groups based on the Mann-Whitney U test).  
 B: Health conditions based on crown symptoms in the different treatment groups (mean values; different labels mean significantly different groups based on the Mann-Whitney U test).  
 C: Lesion sizes in the different treatment groups (mean values; different labels mean significantly different groups based on the Mann-Whitney U test).

## 4 DISCUSSION

The main goal of our study was to determine the causal agents of the selective wild cherry mortality in a mixed deciduous forest stand growing in a flooded riverside area. Initially, the sandy alluvial soil and the impact of the fluctuating water levels were suspected as they represent poor growth conditions for cherry trees. However, various bark cracking and necrosis symptoms in the trees that were still alive indicated a possible *Phytophthora* infection. At the same time, we did not observe any visible symptoms of a potential fungal or bacterial attack, neither in the dead, nor in the dying trees. The recovery of *P. polonica*, from both the necrotic tissues and the rhizosphere soil of the dying trees, suggested a primary role of this *Phytophthora* species in the observed dieback. *P. plurivora*, regarded as a pathogenic species (Oßwald et al. 2014), was also isolated from the soil and was considered as a potential contributing factor to the rapid decline of the trees.

Stem and root infection tests demonstrated the pathogenicity of both *Phytophthora* species, with *P. polonica* showing slightly more virulence against wild cherry seedlings. The significant differences in the root infection between the two different planting media used suggest that the poor site conditions may have led to weakened immunity in the wild cherry trees. The unusually high precipitation in the region, which occurred in August 2011 (112 mm), combined with the loose sandy soil texture, may have caused ideal environmental circumstances that exposed the vulnerable cherry trees to a rapid *Phytophthora* invasion.

Although all cherry trees were planted ones, suggesting that the pathogen may have emerged and been introduced to the forest site from a nursery, the seedlings were indeed grown from local seed resources in a nearby nursery. Therefore, the origin of the pathogen remains still unclear and a recent colonization of the forest site cannot be ruled out.

While *P. plurivora* has previously been associated with the decline of various forest stands in Hungary (Szabó et al. 2013), this is the first report of *P. polonica* being directly involved in rapid tree mortality. Since 2012, no similar decline of wild cherry trees has been reported in Hungary. Nevertheless, our results provide a warning of a potential threat to *Prunus* species and highlight the importance of considering site conditions when planning plantations or reforestations.

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## Root Stability Evaluation with Non-Destructive Techniques

Ágnes Kinga BUZA<sup>a\*</sup> – Ferenc DIVÓS<sup>b</sup>

<sup>a</sup> József Bódig Non-destructive Testing Laboratory, University of West Hungary, Sopron, Hungary

<sup>b</sup> Institute of Physics, University of West Hungary, Sopron, Hungary

**Abstract** – Due to their huge benefits when compared to invasive or destructive techniques, the use of non-destructive approaches is continuously increasing in many fields. The visual assessment method is commonly applied in tree inspection, but it has limitations. Investigations using appropriate non-destructive instruments can well complement visual tree inspection. This paper is a short overview that describes non-destructive techniques for evaluating the load-bearing capacity of individual trees' root systems. The techniques used are acoustic root detection and the pulling test. Safety factors were also calculated to provide a hazard assessment.

**root detection / pulling test / acoustic root detection / safety factor / non-destructive evaluation**

**Kivonat** – A gyökérzet biztonságosságának becslése roncsolásmentes vizsgálati technikákkal.

A roncsolásmentes megközelítés számos területen terjed folyamatosan a roncsolásos technikákhoz képesti előnyeinek hála. A fák vizuális értékelése elterjedten használt, ám ennek megvannak a maga korlátai. A műszeres vizsgálatok jól kiegészíthetik a vizuális méréseket. Jelen cikk egy összefoglaló, mely a biztonságosság és terhelhetőség irányából közelíti meg a fák gyökérzetének vizsgálhatóságát. A bemutatott roncsolásmentes technikák az akusztikus gyökér érzékelés és a húzóvizsgálat. Emellett a biztonsági faktorok számítása is röviden összefoglalásra kerül.

**gyökér érzékelés / akusztikus gyökér keresés / húzóvizsgálat / biztonsági faktor / roncsolásmentes értékelés**

### 1 INTRODUCTION

Trees have played a vital role in human life and civilization for thousands of years; their significance in society and industry is undeniable. The many roles trees play within the human sphere makes the examination of tree conditions an especially important task.

The root system is an 'invisible' part of trees that is crucial to both tree metabolism and stability. There are numerous techniques to study the root system – some are invasive and cause harm to the tree, while others are non-destructive and do not harm the tree. Non-destructive methods have the advantage of repeatability – that is they can be employed more than once on the same tree. Long term study of the root system and growth is becoming possible.

Non-destructive evaluation of trees is an area of non-destructive testing (NDT). Non-destructive evaluations are increasingly being recognized as effective methods for examining

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\*Corresponding author: agnes.kinga.buza@gmail.com; H-9400 SOPRON, Bajcsy-Zs. u. 4. Hungary

the internal conditions of various materials without disturbing or destroying them. Even though some NDT techniques have already become well-proven in research, it takes time for the technology to be implemented in field.

This paper briefly reviews NDT techniques for root stability evaluations. The aim is to present summarized information to help understand the usage and the limitations of these techniques. An instrumental background is required to quantify the effects of injuries and infections (e.g. fungus), or to quantify the sizes or loss of material in the case of decay and cavities. We believe that NDT methods have their benefits and deserve to have wider utilization.

Non-destructive evaluation techniques have been applied with varying objectives in many fields such as urban trees, forestry, ecology, and horticulture.

The main trends in research focus on:

- a) Determining the biomass content of forest, trees or roots and underground biomass content (Morelli et al. 2007; Borden et al. 2014);
- b) Evaluating the safety of individual trees including root systems (Brudi – Wassenauer 2002; Wu et al. 2014);
- c) Determining tree response to static and the dynamic loads such as wind, snow or rockfalls (Dorren– Berger 2005; James – Kane 2008);
- d) Assessing wood quality in standing trees and determining the effect of site conditions, stand age, and silvicultural treatments on wood quality (Wang et al. 2006; Grabianowski et al. 2006; Wang 2013).

Instrumental techniques are diverse according to the aim or/and the use of the measurement.

The major applied non-destructive techniques in root system investigations are pulling tests, ground penetration radar (Guo et al. 2013), and electric resistivity tomography (Amato et al. 2008; Zenone et al. 2008). A comparison of ground penetration radar and pulling tests (Danjon – Reubens 2007) has been reported.

With respect to tree safety, visual assessment has been used to determine the load-bearing capacity of root systems. Several researchers have reported the relationships among the diameter at breast height (DBH), tree height (H) and the stability of roots, anchorage strength, the maximum of force or bending that can be survived without damage. (Some researchers use calculations with standardized, unified force, while in other works bending is the parameter used. If force is applied at different heights, the same force can lead to different bending.)

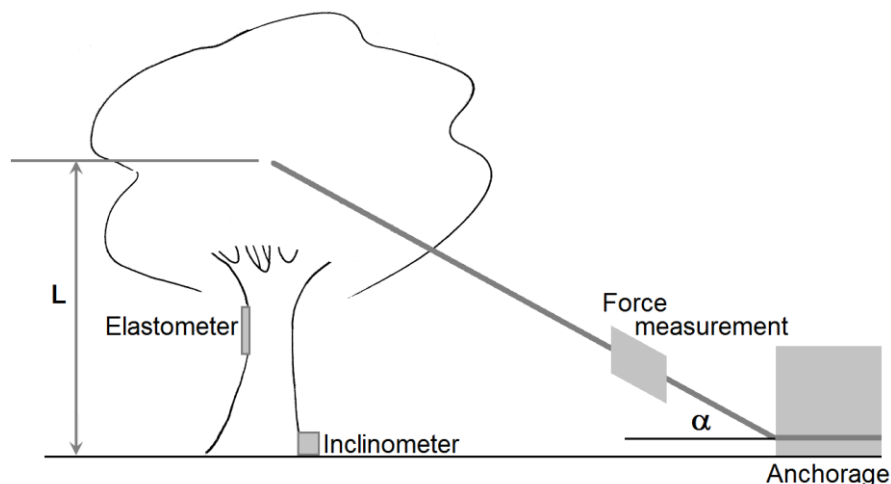
In many experiments the force, or bending moment, causing uprooting or trunk failure was determined. For instance, Peltola and colleagues (2000) pulled over 95 trees (51 Scots pines (*Pinussylvestris* L.), 33 Norway spruces (*Piceaabies* (L.) Karst.), and 11 birches (*Betula* spp.)) and their analysis showed that the second power of DBH multiplied by tree height ( $DHB^2 H$ ) predicted anchorage strength; while the third power of breast height diameter ( $DHM^3$ ) best served for forecasting stem failure. Similar results are presented in the work of Lundstrom and colleagues (2007) who collected data on a total of eighty-four trees (including 57 Norway spruces (*Piceaabies* (L.) Karst.), 23 silver firs (*Abiesalba* Mill) and other species) and stated that the breast height diameter squared times tree height ( $DHB^2 H$ ) is a parameter to forecast root stability. However, Achim and Nicol (2009) found breast height to be an acceptable parameter for predicting anchorage strength.

The instrumental techniques presented in our paper are pulling test and acoustic root mapping; it is possible to predict the root system and stability with both methods. These instrumental methods can also be employed in the evaluation of safety needs calculations on loads (with wind load being the most common) and estimations of the load-bearing capacity of trees. The safety factor is a value quantifying safety to help decide whether a tree should be retained or felled. One way of calculating safety factors is also described in the work of Brudi and Wassenauer (2002).

## 2 PULLING TEST

The pulling or winching test is a method for investigating the root-soil system and root anchorage. Assessing the safety of trees and evaluating stem conditions are other applications of pulling, as well as serving as calibration for measurements in real wind situations. (The moment caused by winching and the created inclination is measured. In wind or storm conditions, the inclination can be measured and the inducing moment, that is the “strength of the wind,” can be evaluated.) Destructive pulling should also be mentioned at this point. With this method, researchers can uproot trees in order to compare different conditions for the bending moment causing failure. Plenty of excellent papers are available on the implementation and the usage of these tests (Bell et al. 1991; Wessolly 1991; Rodgers et al. 1995; Ray – Nicoll 1998; Neild – Wood 1999; Moore 2000; Peltola et al. 2000; Silins et al. 2000; Brudi – Wassenaer 2002; Clair et al. 2003; Lundström et al. 2007A; Lundström et al. 2007B; Kane – Clouston 2008; James – Kane 2008; Sani et al. 2012; Siegert 2013; James et al 2013; Rahardjo et al. 2014).

During a pulling test (*Figure 1*) a cable is generally placed on the tree as close as possible to the crown center or half of the trunk. The other end of the cable should be anchored to another tree or other object, and the applied force should be measured. During the test, a pulling force is applied through the cable to bend the tree and the inclination, elongation, and dislocation of the ground are monitored and measured. (Elongation is usually measured along the trunk at higher levels as seen in *Figure 1*. As the stem bends, it elongates as well. Conditions of the trunk can be evaluated. Dislocation of the ground is caused by the roots as they move and/or break during the pulling. Measurements can be performed on the ground near the winched tree.)



*Figure 1. The schematic diagram of a pulling test. The cable should be anchored in a secure object for the test.  $L$  is the height of the cable's anchor point at the center of the crown*

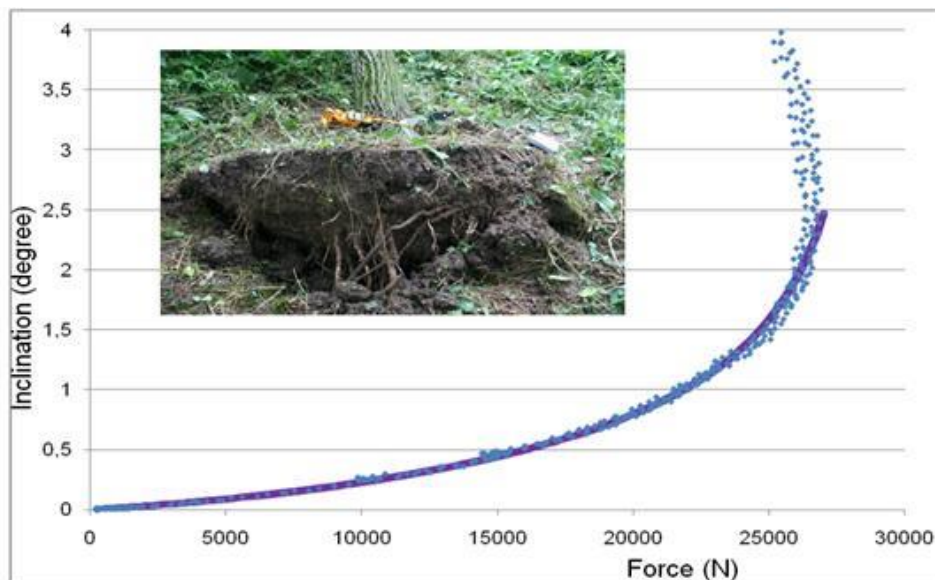
The inclination of the tree's trunk should be measured if the purpose of the testing is to evaluate the risk of tree uprooting. The inclinometer should be fixed to the trunk at ground level. (At higher levels the trunk's elastic deformations modify the results. A ratchet strap can go around the trunk and fix a flat little “shelf” which folds the inclinometer. If the fastening is tight, the inclinometer moves with the trunk.)

The pulling test usually continues until the inclination of the trunk at ground level reaches 0.020-0.6 degrees. The collected force-inclination data should be filtered according to the relaxation of the tree. (Winching stresses the tree, causing inclination; although relaxation of the wood material of the tree does occur. For the evaluation of safety, only the inclinations immediately responsive to the pulling are used. Inclination data that are collected during the

relaxation effects should be neglected.) (Divós et al. 2009; Sani et al. 2012; James et al. 2013). The difference between trees can be stated clearly, even for the same species at the same field; the measured pulling moment ranges between 0.07 and 0.6 degrees. The force used and the caused moment were higher for trees whose tilt was 0.07, which refers to more enormous anchorage strength than trees that tilted 0.6 degrees for weaker winching. (James et al. 2013)

The pulling of a tree should be less than 0.25-0.6 degrees to avoid injuring the roots. (This range is quite great according to the difference of trees.) Coutts (1983) found that the first sound indicating root breaking started at a 0.5 tilt. Rahardjo and colleagues (2014) established a model of tree felling based on their field experiences. They also verified roots breaking during uprooting and stated root cross-sectional area and root plate radius to be relevant for root anchorage evaluations. Modeling focusing on root failure (shape and stresses) was presented by Lundstrom and colleagues (2007B).

Brudi and Wassenaar (2002) reported that irreversible failures usually occur above 2 degrees of inclination. Nearly no additional force is needed to pull a tree over from 2 to 40-60 degrees. Lundstrom et al. (2007B) found that the maximum bending moment is observed between 2-15 degrees. An example of turning out is seen in *Figure 2*. The maximum tilt reported was 0.9 degrees in wind gusts up to 90 km/h, while 0.5-0.6 degrees were declared as average (James et al. 2013).



*Figure 2. An example of uprooting (shown in the photo) and the pulling test data. (Divós et al. 2009)*

After a pulling test, the whole tree should return to its original position. However, a complete recovery from a pulling test can take several minutes (James et al. 2013). Bending of the trunk was studied for Sitka spruce both in the field and with models by Neild and Wood (1999) who found out root flexibility is a non-negligible factor in pulling testing.

Pulling tests can also be performed on trees with buttresses. The stability of the trees was found to be lower for pulling tests conducted on the buttress sides (Clair et al. 2003).

Soil conditions can affect tree stability measured by pulling tests as it is described in the work of Moore (2000) and Bergeron and colleagues (2009).

Temperature conditions, particularly frozen soil and frozen trunks, will affect pulling testing. For instance, Silins and colleagues (2000) performed the pulling test to determine strength in frozen and unfrozen conditions. Peltola and colleagues (2000) declared that a higher bending moment is needed to break the stems of trees in frozen conditions (no turn out happened).

Wind gusts cause different moments compared to pulling tests (which are static). Tree failures were reported at 17.5 m/s wind speeds, which were less than the pulling test predicted (James – Kane 2008). (The study of the behavior of groups of trees under windy conditions started as well. Schindler (2008) measured movements of 10 nearby trees during windy conditions and wrote down an analysis of crown interactions.)

Pulling tests can also be used to evaluate trunk conditions at different levels. The pulling happens in the same way while the measurements are done on the trunk, on the stem using elastometers, prisms, accelerometers, or other equipment (Wessolly – Erb 1998; Brudi – Wassenaer 2002; Moore et al. 2005; Hagrey 2006; James et al 2013).

The main limitation of the pulling test is its static nature of loading. Wind usually comes in gusts and is dynamic in nature. The pulling test also requires heavy equipment. For an overall evaluation of a tree, a pulling test should be performed in two perpendicular directions, which may not be possible due to the surroundings found in some environments (Brudi – Wassenaer 2002, Sani et al 2012).

In urban areas, the most common usage of a pulling test is to predict the safety of the trees in windy conditions without uprooting the tree or even without decreasing safety. A safety factor calculation used in urban areas is shown in the next section.

### 3 SAFETY FACTOR

Safety factors give us information about tree stability. The simplest definition for safety factor (SF) is given by *Equation 1*. SF is the ratio of the evaluated capacity and the calculated load (wind, snow, effects of gravity (Gardiner et al. 2000)). SF helps us to evaluate the measurements in the perspective of safety. SF is usually a number or a percent. Regarding trees, safety factors can be established for uprooting, and for trunk breaking.

$$SF = \text{capacity of the tree} / \text{estimated load} \quad (1)$$

The estimations presented in this section are the estimations of wind loads for trees (tree surfaces) and load bearing capacities of root systems estimated from pulling tests. The calculations are simplified; however, they have proved their usefulness in numerous field experiences in the work of Wessolly (1991), Brudi and Wassenaer (2002), Divós and his colleagues (2009), Buza and Göncz (2015).

According to the estimations, during the measurements and the calculations, a safety factor for a tree is considered good from 1.5 to 150%. (An assessment of “good” refers to retaining the tree.)

#### 3.1 Wind load for trees

Wind is the most common load of trees. As the wind reaches the surface of the crown and the stem, it causes a moment to which the tree should respond. The moment of wind load is estimated by *Equation 2*.

$$M_{\text{wind}} = f c^{1/2} \rho \sum \{u(z)^2 h(z) A(h(z))\} \quad (2)$$

where  $f$  is the natural frequency factor,  $\rho$  [kgm<sup>-3</sup>] denotes the air density,  $u(z)$  [ms<sup>-1</sup>] expresses the wind velocity,  $h(z)$  [m] is the height of unit-area at a specific position in crown surface,  $A$  [m<sup>2</sup>] is the crown surface at respective height, and  $c$  is the aerodynamic drag factor.

Note that wind speed and air density depend on the geographical and the topographical situation as well as the seasonal and meteorological influences.

### 3.2 Safety factor for the root system for uprooting

Evaluation of SF for uprooting is based on pulling and uprooting experiments. Force and inclination data are collected during the pulling test. These data should be filtered according to the relaxation of the tree. For the description of the relationship between the applied force and the inclination of the trunk at ground level during uprooting tests, a tangential function proved suitable.

This function can be fitted to the filtered data and shown by *Equation 3*.

$$\varphi_{\text{calc}} = 0.33 \tan ( F / F_{\text{tip}} ) + 0.5 ( F / F_{\text{tip}} )^2 - 0.1 ( F / F_{\text{tip}} ) \quad (3)$$

where  $\varphi_{\text{calc}}$  is the fitted inclination,  $F$  [N] is the measured force and  $F_{\text{tip}}$  [N] is the evaluated tipping force. (See the filtered data in *Figure 2*.)

The moment which could uproot the tree is

$$M_{\text{tip}} = F_{\text{tip}} L / \cos \alpha \quad (4)$$

where  $L$  [m] is the cable's height on the examined tree and  $\alpha$  is the cable's degree (*Figure 1*).

Based on *Equation 1*, the following equation can describe the SF for the root system for uprooting calculated from a pulling test.

$$SF_{\text{root}} = M_{\text{tip}} / M_{\text{wind}} \quad (5)$$

The presented calculations are used after pulling tests as well for the evaluation of tree safety along streets, in parks, or in other situations. Advice regarding the retaining or felling of a tree can really help the work of the gardeners.

## 4 ACOUSTIC DETECTION OF ROOTS

Acoustic detection of roots is a technique inspired by other acoustic techniques (time-of-flight measurement, tomography; Grabianowski et al. 2006; Wang 2013) used for tree evaluation. The method has been developed at the University of West Hungary and the new method has been tested in the university's botanical garden (Divós 2008).

The physical background of the measurement is the velocity-difference in wood and soil. The acoustic signal's velocity in soil is about 250-400 m/s depending on soil type and moisture content, while the velocity in the roots is between 2000 and 4000 m/s (Bucur 1995; Divós et al. 2009).

Based on these differences, models have been constructed to estimate the acoustic signal's path in both pure soil and the soil containing roots. After successful experiments, a set-up for field usage has been designed. The device consists of a transmitter, a receiver, and a time-measuring component. The transmitter is needle-like and should be placed onto the trunk at ground level, while the receiver is a long metal spike (30 cm or longer), which has a good coupling for the soil (*Figure 3*) (Divós et al. 2009; Buza – Göncz 2015).

At realization of acoustic detection, a very short signal (an 'acoustic flash') is sent from the transmitter to the tree and to the roots. The time measure turns on. When the receiver detects the arrival of the acoustic signal, the time measure stops. When a root is nearby (closer than 10 cm), the travel time decreases significantly. The depth of the root can be estimated as well. This technique can find roots from 4 cm diameter and can separate two roots from each other if there is at least 20 cm distance between them (Divós et al. 2009). The maximum depth for detection is 50 cm.

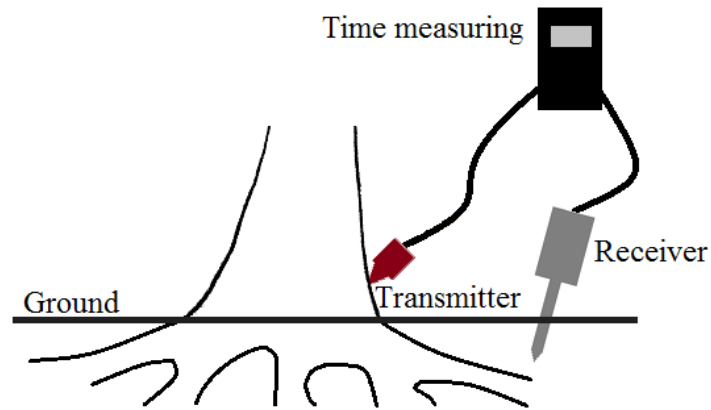


Figure 3. Acoustic root detection needs a transmitter placed on the trunk near to the ground and a receiver which can be stuck into the ground. The transmitter generates an acoustic signal which travels through the wood material. If the receiver is near a root, the traveling time of the signal changes significantly.

The measure is usually performed along a circle around the trunk, with a step of 10-15 cm. The measurement is repeated along wider and wider circles. The direction of the roots can be marked by sand or typed to a program. An example of root detection is seen in Figure 4 and 5. A comparison of predictions of the theoretical model and the measured data were performed; contrasting of evaluated root system and real root situation was completed as well. The roots were excavated and the 3D model of the evaluated root system fit well to the roots found by uncovering.

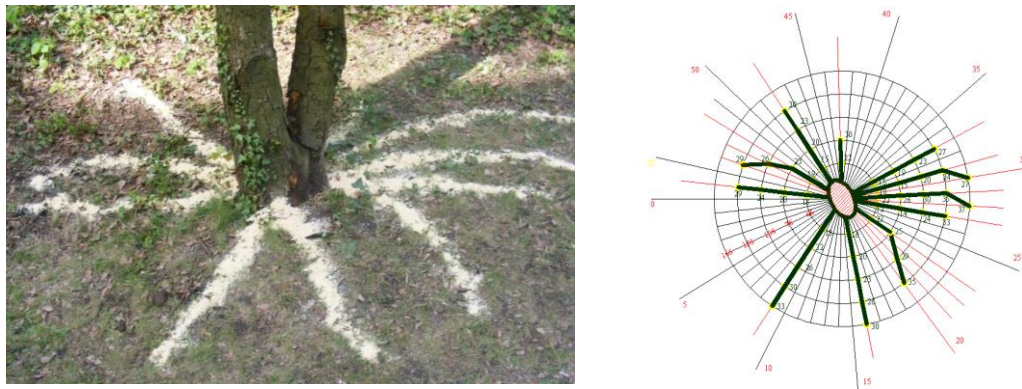


Figure 4. A measured tree in the botanical garden of the University of West Hungary (left) and the root map calculated by the program (right) (Divós 2008)



Figure 5. The 3D model of the root system (left) compared to the result of excavation (right) (Divós et al. 2009)

In further measurements, the area reached by the roots was evaluated and compared with

safety factors from the pulling test. The calculated data were different; however, the results of acoustic root detection seem to be in correlation with the safety factors predicted by the pulling test. For instance, the ratios of the data for two trees were 1.68 from the pulling test and 1.53 from acoustic root detection. This is a difference about 10%; however, the ratios are promisingly close (Buza – Göncz 2015).

Limitations of the presented technique are clear; roots with diameters smaller than 4 cm are not seen by acoustic detection, and the maximum depth of the measure is about 0.5 m. Nevertheless, compared to other available techniques like ground penetration radar (GPR) or electric resistivity tomography (ERT), acoustic root detection has a remarkable advantage; the roots of the measured tree are detected. Signals of GPR and ERT both change in the presence of a root. However, GPR and ERT signals also change even if tubes, rocks, or other materials are buried (Hruska – Cermak 1999; Cermak et al. 2000; Stokes et al. 2002; Hirano et al. 2008).

## 5 SUMMARY

Non-destructive tests can provide quantifiable information about the inner conditions of trees. As the trees are not injured during the tests, repeated measurements and long term monitoring are possible as well. Safety is an important topic as tree failure can cause property damage or harm to humans.

NDT techniques were presented for the evaluation of root system safety; the pulling test was described along with the calculation of safety factors. Acoustic root detection was also presented.

Even though real wind is different from static tests, a pulling test can be used to evaluate the moment the wind load needed to turn out the trees is achieved. Usages, possibilities, and limitations of the pulling test were summarized in this paper.

One of the advantages of acoustic root detection is its ability to find the root of a selected tree, but it can also be utilized as a tool for safety evaluations.

Predicting the conditions of root systems is an area where complex knowledge is needed to get useful results. By collecting information about the mentioned techniques, our aim was to present the work occurring at the University of West Hungary, where the acoustic root detection method was developed, and to help involved researchers understand the available measurements and their limitations.

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## Bondability of Beech Wood with One-component Polyurethane Structural Adhesive

Norbert HORVÁTH<sup>a\*</sup> – Csilla CSIHA<sup>b</sup>

<sup>a</sup> Institute of Wood Science, University of West Hungary, Sopron, Hungary

<sup>b</sup> Institute of Wood Products and Technologies, University of West Hungary, Sopron, Hungary

**Abstract** – The bondability of beech (*Fagus sylvatica* L.) wood with a one-component polyurethane (1K PUR) structural (load-bearing) adhesive has been investigated at the Simonyi Károly Faculty at the University of West Hungary. Our trial is considered a preliminary investigation in order to set the convenient parameters of bonding for the structural gluing of beech wood. Wood samples were characterized by their oven dry density, and the surfaces to be bonded were characterized by their surface roughness and surface tension after machining. Based on our measurements, we have made a suggestion on the value of the ensemble of open time, applied quantity and pressure, pressing time, and surface preparation/surface roughness parameters which result in good bonding and a shear strength higher than 10 N/mm<sup>2</sup>. Furthermore, we investigated the penetration of the adhesive into the surface and state that one-sided adhesive application results in differing levels of penetration. In order to check the suitability of beech wood for glued laminated timber production, further investigations according to EN standards are necessary. Based upon the considerations noted above, delamination tests are already under evaluation.

***Fagus sylvatica* / load-bearing glued laminated timber / bondability / penetration**

**Kivonat** – Bükk faanyag ragaszthatósága egykomponensű poliuretán szerkezeti ragasztóval. Bükk (*Fagus sylvatica* L.) faanyag ragaszthatósági vizsgálatait egykomponensű poliuretán (1K PUR) szerkezeti ragasztóval a Nyugat-magyarországi Egyetem Simonyi Károly Karán végeztük. Vizsgálatuk a bükk faanyag szerkezeti ragasztásához megfelelő paraméterek beállításához szükséges előzetes kísérletnek tekinthető. A famintákat abszolút száraz sűrűséggel a ragasztandó felületeket pedig a felületi érdességgel és felületi feszültséggel jellemeztük. Méréseink alapján javaslatot tettünk a nyílt idő, a felhordott ragasztómennyiség, a présnyomás, a présidő a megmunkálás/felületi érdesség, a faanyag nedvességtartalom, illetve a felületi feszültség paraméterek együttesének olyan értékére, mely mellett a ragasztás elvégezhető és a ragasztott kötés nyírószilárdsága nagyobb, mint 10 N/mm<sup>2</sup>. Vizsgáltuk továbbá a ragasztó penetrációját a faanyagban, és megállapítottuk, hogy különbség van az egyoldalas és a kétoldalas ragasztó felhordás esetén előálló behatolási mélységek között. A bükk faanyag rétegelt-ragasztott tartók gyártására való alkalmasságához további, az MSZ EN szabvány szerinti vizsgálatok is szükségesek. Ezen megfontolások alapján a rétegeltválás (delamináció) vizsgálatok értékelése már folyamatban van.

***Fagus sylvatica* / rétegelt-ragasztott szerkezeti fa / ragaszthatóság / behatolási mélység**

\* Corresponding author: norbert.horvath@skk.nyme.hu; H-9400 SOPRON, Bajcsy-Zs. u. 4. Hungary

## 1 INTRODUCTION

In Europe, coniferous species are the most commonly used species for glued laminated timber production. Yet according to Wittmann (2000), theoretically, no species can be excluded from the field of structural application. However, economic considerations, structural specificities, and other requirements set some limitations and the use of all species is not justified. Ebener (2001) points out that 60–75% of German sawn timber production meant for construction purposes are coniferous species, and the proportion of classical construction timber, length jointed timber, and other glued laminated timber reaches 30–50%. Furthermore, he emphasizes that the need for glued laminated structural timber is increasing.

Numerous tests have been conducted regarding structural gluing of beech wood in order to answer whether the wood material of broadleaved species is suitable for glulam structural element production and what the generally valid gluing parameters of fluent production technology are (Frühwald et al. 2003, Blaß et al. 2005, Frese 2006). Frühwald et al. (2003) tested six layer glulam beams, steaming the beech lamellas before gluing in order to homogenize color deviations originated from redheart and to decrease internal tension existing in the wood material. They found that beech can be a key important raw material for slim structures as it possesses good mechanical properties, but it should be used primarily indoors due to its limited durability.

Besides the use of coniferous species, there is an international trend towards the use of hardwoods for structural purposes; this is supported by intense research activity. Ohnesorge (2009) published comprehensive results on the usability of beech (*Fagus sylvatica* L.) wood bonded with PUR, MUF, PRF structural adhesives for structural purposes. His investigations targeted both the strength of the bond and the delamination as well. According to his results, when determining the shear strength of the samples prepared according to MSZ EN 14080, the breakage of grains was around 15% in the case of the PUR adhesive, around 91% in the case of PRF adhesive, and around 81% in the case of MUF adhesive. Furthermore, he stated that neither heartwood nor steaming exert a relevant effect on the bondability of MUF adhesives. In addition to this, he pointed out that by choosing a convenient open time and a maximized lamella thickness of 30 mm, good bondline strength can be achieved.

Along with the successful bonding of different hardwood species, delamination behavior is another issue that needs to be considered; thus, several investigations have been conducted in order to increase the bond strength and to decrease the delamination by using surface-activating agents (Csiha et al. 2010) or by changing the chemical status of the wood surface by treatments like plasma or laser (Gerstenberg – Viöl 2005). Improvements have also been reported by using hydroxy-methylated resorcinol (HMR polymer) (Vick et al. 1995, Christiansen et al. 2003, Christiansen 2005, Eisenheld – Gardner 2005). López-Suevos and Richter (2009) observed significantly reduced delamination of glue laminated eucalypt timber (*Eucalyptus globulus*) when bonded with HMR primer.

## 2 MATERIALS AND METHODS

### 2.1. Wood species investigated

The investigations have been performed in order to gain information regarding the bondability of beech wood with the available 1K PUR structural adhesive. Wood samples have been characterized by their oven dry density and the surfaces to be bonded have been characterized by their surface roughness and surface tension after machining.

Primarily, beech (*Fagus sylvatica* L.) is a central European wood species, but is also present in Britain and southern Scandinavia between the 40° and 60° latitudes. In the north it

also grows on the low plains, but generally it is considered a wood species of hilly-mountain regions at 600–800 m altitude. In Hungary beech forms coherent stands in Északi-középhegység (the mountains east of the Danube), Magas-Bakony (the highest part of the Bakony), Zala County, Mecsek, Zselicség, Kőszeg and Sopron Mountains (Molnár – Bariska 2006).

## 2.2. Wood samples and adhesive

A total of 50 lamellas of 15 mm thickness were prepared by planing from defect free specimens of beech wood. They were conditioned at room temperature (20 °C air temperature, 60% relative humidity). The chosen adhesive was the Jowat 686.60 type 1K (PUR) adhesive, frequently used by industry for structural bonding of coniferous species (except larch). The lamellas were glued together at one side using 220 g/m<sup>2</sup> of adhesive application, 30–40 minutes open assembly time, 1 N/mm<sup>2</sup> of pressure, and 3 hours of pressing time (closed assembly time of 6–8 min).

### 2.2.1 Determination of moisture content and density of the samples

For the measurement of net moisture content (MC) and respective density after conditioning at normal climate, 20 mm × 20 mm (perpendicular to the grain) and 30 mm parallel to the grain prism-like samples were prepared. In order to measure their size and weight, a digital caliper and a digital balance were used, both with measuring accuracy down to 0.01. Drying of samples was performed in a drying chamber at 103 ± 2 °C air temperature. The values were calculated by the following formulas (1 and 2):

$$MC = \frac{m_x - m_o}{m_o} \cdot 100 \quad (1)$$

Where:

MC is the moisture content in %

$m_x$  is the wet mass in g

$m_o$  is the oven dry mass in g

$$\rho_0 = \frac{m_0}{l_0 \cdot r_0 \cdot t_0} \cdot 10^6 \quad (2)$$

Where:

$\rho_0$  density of the absolute dry samples, in kg/m<sup>3</sup>

$l_0$  the size of the absolute dry samples parallel to the grain, in mm

$r_0$  the size of the absolute dry sample in radial direction, in mm

$t_0$  the size of the absolute dry sample in tangential direction, in mm

$m_0$  the weight of the absolute dry sample, in g

### 2.2.2 Surface roughness measurement

The measurements were performed on the planed surface of the samples with 150 mm × 50 mm × 15 mm dimension. A total of 50 roughness measurements were performed, one on each sample, using a Mahr Perthen SP 3 instrument equipped with a stylus tip of 5 µm radius (Figure 1). The instrument calculates the roughness parameters automatically using a Gaussian filter.



### 2.2.3 Surface tension measurement

Surface tension was measured by means of a PGX Goniometer, taking 10 measurements on each sample type. During the measurements, a drop of liquid was placed on the surface of wood sample. It was assumed that the liquid does not react with the solid. It was emphasized that contrary to ideal smooth surfaces, the drop of water is distorted along the grains, taking a form of a semi oval sphere. The volume of the measuring drop was of 0.4  $\mu\text{l}$ , and the contact angle was automatically detected and measured at 1 sec after the release of the droplet, as previously agreed. Distilled water was used as the test liquid. The measuring instrument was calibrated before each measurement. The contact angle was measured as the angle between the outline tangent of the smaller diameter and surface. The surface free energy was automatically calculated by the computer equipped Goniometer.



Figure 4. A PGX goniometer for surface tension measurement

### 2.3 Pressing of samples

The application of the adhesive and pressing of samples were performed in the workshop of the UWH, Simonyi Károly Faculty of Engineering, Wood Science and Arts. The adhesive was applied at room temperature at 65% relative humidity. The chosen amount of adhesive according to the technical datasheet was 220  $\text{g}/\text{m}^2$ . It was applied on one side with a roller within an open time of 30–40 min. A total of 24 samples were prepared using a Stromab STH hydraulic press (Figure 5) in one step pressing, by stacking the samples. The pressing load was 1.0  $\text{N}/\text{mm}^2$ , with a pressing time of 3 hours.



Figure 5. The Stromab STH press

## 2.4 Determination of the bond strength

Samples suitable for shear strength measurement were prepared according to MSZ EN 302-1 (Figure 6). The samples were acclimatized according to MSZ EN 302-1 for 7 days at room temperature (20°C temperature and 65% relative humidity) and tested afterwards. The shear strength was determined by using a TiniusOlsen H10K type instrument (Figure 7). The area that was supposed to shear on each sample was measured by digital calliper. The shear strength of the 24 samples was calculated using the following equation:

$$\tau = \frac{F_{\max}}{A} [\text{N/mm}^2] \quad (3)$$

Where:

$F_{\max}$  the maximal force, in N

$A$  the area of the exposed portion, in  $\text{mm}^2$

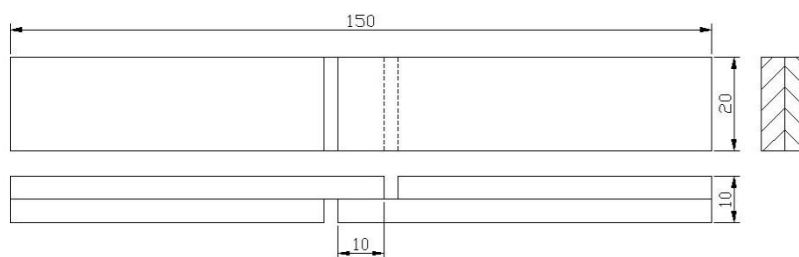


Figure 6. Sample for shear strength measurement according to MSZ EN 302-1

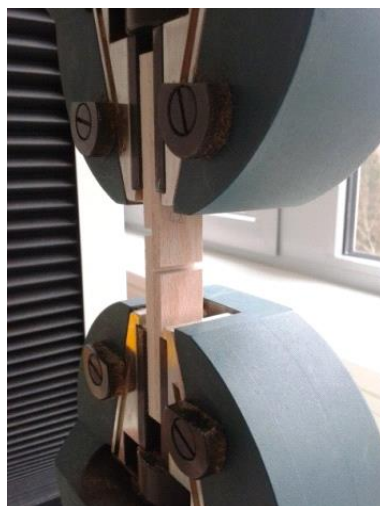


Figure 7. TiniusOlsen H10K instrument with a sample

## 2.5 Determination of adhesive penetration

For the determination of adhesive penetration, a Nikon SMZ800 microscope was used (Figure 8). Samples that were 10 mm thick were cut perpendicularly to the grain as the falling end from the glued samples right after the stock was taken out of the press. During the investigation, microscope images were taken from the butt end of the glued samples, and thus from the glue line aided by an Image Pro software.



Figure 8. Nikon SMZ800 microscope

### 3 RESULTS AND DISCUSSION

The investigations were performed in order to gain information regarding the bondability of beech wood with the available 1K PUR structural adhesive as the chosen adhesive (Jowat 686.60 type 1K (PUR)) is frequently used by industry for structural bonding of coniferous species (except larch). The thickness of the glueline was around 0.3 mm, lower than the maximum suggested by the adhesive manufacturer. The average density of the samples was  $735 \text{ kg/m}^3$ , which is typical for beech wood. The average MC of the samples was 9.22%. There were some samples with MC around 8–9%, but later on they did not show any difference in their shear strength suggesting that the reaction of the PUR adhesive was performed without any obstacle in their case also. The pressing load used was  $1.0 \text{ N/mm}^2$ , while the pressing time was 3 hours. The shear strength of the bond and the penetration of the adhesive were determined. In each shear test, the wood broke, meaning that the adhesive bond was stronger than the cohesion of the beech wood material.

#### 3.1 Results of surface roughness and surface tension

The surface roughness of the planed beech surfaces was influenced both by machining – planing in this case – and the tissue structure of the wood. The average surface roughness of the samples is given in Table 1.

Table 1. Contact angle, surface tension and surface roughness ( $R_a$ ,  $R_z$ ,  $R_{max}$ ) of planed beech samples

|          | Contact angle<br>( $^{\circ}$ ) | Surface tension<br>(N/m) | $R_a$<br>( $\mu\text{m}$ ) | $R_z$<br>( $\mu\text{m}$ ) | $R_{max}$<br>( $\mu\text{m}$ ) |
|----------|---------------------------------|--------------------------|----------------------------|----------------------------|--------------------------------|
| Average  | 72.73                           | 38.8                     | 6.52                       | 50.45                      | 67.31                          |
| st. dev. | 20.79                           | 7.61                     | 1.43                       | 8.7                        | 17.05                          |

### 3.2 Results of bond strength

Samples were subjected to pulling and thus shear stress was induced. In each case the wood broke, meaning that the adhesive bonding was stronger than the cohesion of the beech wood material. The values of the shear strength are as per *Table 2*.

*Table 2. The shear strength of the samples (parallel to the grain)*

|                                     | Average | St. dev. | Min   | Max   |
|-------------------------------------|---------|----------|-------|-------|
| Shear strength (N/mm <sup>2</sup> ) | 16.79   | 4.05     | 11.08 | 29.38 |

### 3.3 Results on adhesive penetration

According to the images taken, the adhesive penetrated twice as deep with direct application (334.23  $\mu\text{m}$ ) than it did with indirect adhesive application. (*Table 3*) The thickness of the glueline was around 280  $\mu\text{m}$ , lower than the maximum suggested by the adhesive manufacturer.

*Table 3. Adhesive penetration*

|                                                 | Average | St. dev. | Min   | Max    |
|-------------------------------------------------|---------|----------|-------|--------|
| Direct adhesive application ( $\mu\text{m}$ )   | 334.23  | 154.28   | 97.14 | 647.60 |
| Indirect adhesive application ( $\mu\text{m}$ ) | 149.19  | 63.89    | 45.33 | 304.40 |

## 4 CONCLUSIONS

Surface roughness and surface tension measurements were also performed. The average surface roughness of the samples was: ( $R_a$ ) 6.52  $\mu\text{m}$ , ( $R_z$ ) 50.45  $\mu\text{m}$  and ( $R_{\text{max}}$ ) 67.31  $\mu\text{m}$  associated with an average surface tension of 38.80 N/m. The samples possessing the above characteristics were glued together with a Jowat 686.60 1K PUR structural adhesive. The average value of the shear strength was 16.79 N/mm<sup>2</sup>, while the lowest value was 11.08 N/mm<sup>2</sup> (*Table 2*).

According to the results, the strength of the adhesive suits level A1 (EN 301). As evidenced in the images taken, the adhesive penetrated twice as deep on the side of direct application (334.23  $\mu\text{m}$ ) than it did on the side of indirect adhesive application (*Table 3*). Although the shear test results were satisfactory, the information is relevant for future investigations regarding the measurement of shear strength in light of adhesive penetration.

Based on the above mentioned results, one can state that planed beech surfaces that have 9.22% average MC, 735 kg/m<sup>3</sup> average density, average roughness of  $R_z = 50.45 \mu\text{m}$ , surface tension of 38.80 N/m with Jowat 686.60 type 1K (PUR) adhesive of 220 g/m<sup>2</sup> quantity applied to one side, open time of 30–40 min, closed time of 6–8 min, and pressing time of 3 hours, that bonding can be performed without obstacles. Also, at dry strength a higher value than 11 N/mm<sup>2</sup> can be expected.

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# A Methodology for Experimental Research of the Freezing Process of Logs

Nencho DELIISKI\* – Natalia TUMBARKOVA

Department of Woodworking Machines, Faculty of Forest Industry, University of Forestry, Sofia, Bulgaria

**Abstract** – This paper describes a methodology for experimental research of the change in the temperature and humidity of the air processing medium and also in the temperature at 4 points of the longitudinal section of logs during freezing. The suggested methodology is used to research the change in the mentioned parameters of poplar logs with diameters of 240 mm, lengths of 480 mm and moisture content above the hygroscopic range during 50 h of freezing in a freezer at a temperature of about  $-30^{\circ}\text{C}$ . The automatic measurement and recording of the parameters is carried out with the help of Data Logger type HygrologNT3 produced by the Swiss firm ROTRONIC. The precise instrumentation allowed, for the first time ever, the measuring of the impact the latent heat released by the free water on the log had on the warming up of the wood during water crystallization in the logs.

**poplar logs / freezing / temperature distribution / automatic measurement / latent heat**

**Kivonat – Rönkfagyasztás kísérleti kutatásának módszere.** Ez a cikk leírja a hőmérséklet és a nedvességtartalom változását levegőben elhelyezett rönk fagyasztásakor, és mutatja a hőmérsékletet hosszirányban lévő 4 különböző pontban. A javasolt módszert használtuk, hogy megvizsgáljuk a fenti paraméterek változását 240 mm átmérőjű, 480 mm hosszú, nedves állapotú nyár rönkök fagyasztási vizsgálatánál  $-30^{\circ}\text{C}$  körüli hőmérsékleten, 50 órás időtartamon. A paraméterek automatikus mérése és rögzítése a svájci ROTRONIC cég által gyártott HygrologNT3 eszközzel történt. A pontos mérőrendszerrel, első alkalommal sikerült megmérni a megfagyó víz által kibocsátott látens hőnek a faanyagot felmelegítő hatását.

**nyár rönkök / fagyasztás / hőmérséklet eloszlás / automatikus mérés / latens hő**

## 1 INTRODUCTION

The duration and energy consumption required for the thermal treatment to plasticize logs for veneer production depends on the degree of the icing of the log (Chudinov 1966, 1968, Shubin 1990, Požgaj et al. 1997, Trebula – Klement 2002, Videlov 2003, Pervan 2009, Deliiski – Dzurenda 2010, Deliiski 2013b).

In the specialized literature, there are limited reports about an experimentally determined or computed temperature distribution of frozen logs subjected to defrosting (Steinhagen 1986, 1991, Steinhagen et al. 1987, Steinhagen – Lee 1988, Khattabi – Steinhagen 1992, 1993, 1995, Deliiski 2004, 2005, 2009, 2011, 2013a, Deliiski – Dzurenda 2010, Deliiski et al. 2014, 2015a,

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\* Corresponding author: deliiski@netbg.com; 1756 SOFIA, Kliment Ohridski Blvd. 10, Bulgaria

2015b) and there is no information at all about the experimentally determined temperature distribution in logs during their natural or artificial freezing. That is why the experimental research and the multiparameter study of the freezing process of logs are of considerable scientific and practical interest.

The aim of this work is to suggest a methodology for experimental research of the freezing process of logs and to present the first results from its usage for precise temperature and humidity change measurements of the air processing medium,  $t_m$  and  $\phi_m$ , respectively. This applies also for measurement of the non-stationary temperature distribution in 4 characteristic points of the longitudinal section of poplar logs during their many hours in a freezer with an adjustable temperature range from  $-1\text{ }^{\circ}\text{C}$  to  $-30\text{ }^{\circ}\text{C}$ . An important part of the work is to present and analyze, for the first time ever, the measuring of the experimentally determined impact the latent heat released by the free water on the log had on the warming up of the wood during water crystallization in the logs.

## 2 MATERIAL AND METHODS

The logs subjected to experimental research had a diameter of 240 mm and a length of 480 mm. They were produced from the sap-wood of freshly-felled poplar trunks (*Populus nigra* L.) with a diameter of 630 mm according to a scheme given on Figure 1 (left).

Before the experiments, 4 holes with diameters of 6 mm and of different lengths were drilled into each log (Figure 1 – right and Figure 2). Sensors with long cylindrical metal casings were positioned in these 4 holes to measure the temperature of the wood during the experiments. The number of the characteristic points, in which the changes in the wood temperature were measured, was limited by the number of available temperature sensors the automatic system used for the experiments had.

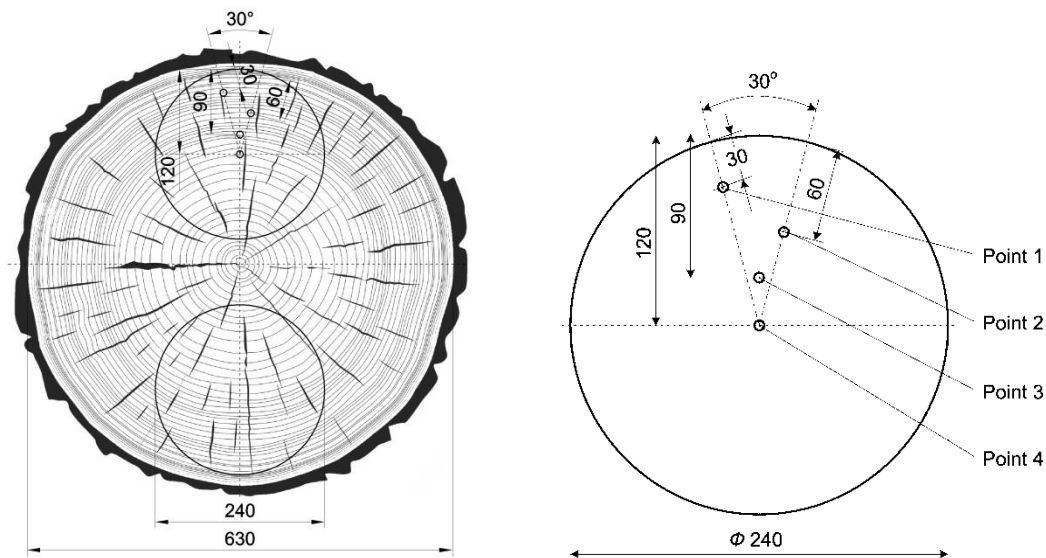
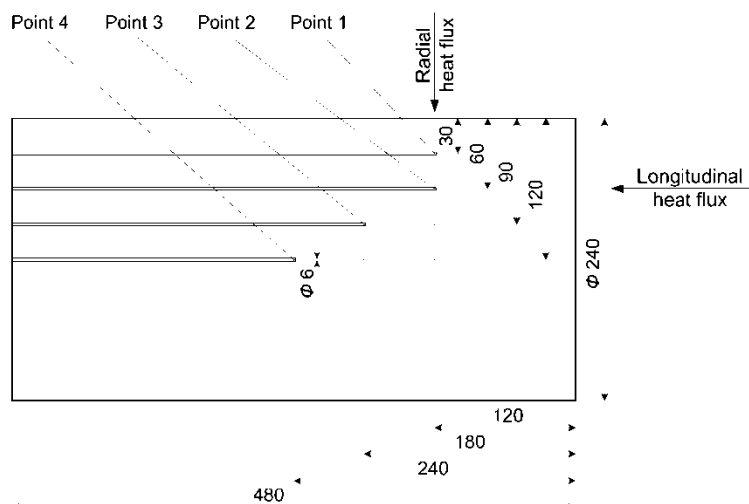


Figure 1. An approach for the production of logs for the experiments (left) and radial coordinates of 4 characteristic points for measurement of the temperature in the logs (right)

The coordinates of the characteristic points of the logs are, as follows:

Point 1: along the log radius  $r = R/4 = 30\text{ mm}$  and along the log length  $z = L/4 = 120\text{ mm}$ ;  
 Point 2: along the log radius  $r = R/2 = 60\text{ mm}$  and along the log length  $z = L/4 = 120\text{ mm}$ ;  
 Point 3: along the log radius  $r = 3R/4 = 90\text{ mm}$  and along the log length  $z = 3L/8 = 180\text{ mm}$ ;  
 Point 4: along the log radius  $r = R = 120\text{ mm}$  and along the log length  $z = L/2 = 240\text{ mm}$ .

These characteristic point coordinates allow for the impact of the heat fluxes to be simultaneously covered in radial and longitudinal directions on the temperature distribution of freezing logs (*Figure 2*). Point coordinate values that were suitable for temperature computation and visualization in these points were chosen with the help of a 2D model of the freezing process of the logs aimed at its verification (Deliiski et al. 2014).



*Figure 2. Longitudinal section of log with drilled holes for positioning of sensors for measurement of the wood temperature during the freezing process*

Each log prepared for the experiments was placed in a PVC bag with the aim of homogenizing the moisture content in its volume as far as possible. Following this, the experiments began.

To freeze the logs, a horizontal freezer with length of 1.1 m, width of 0.8 m, depth of 0.6 m and adjustable temperature range from  $-1\text{ }^{\circ}\text{C}$  to  $-30\text{ }^{\circ}\text{C}$  was used (*Figure 3 – left*).

The automatic measurement and recording of the temperature and humidity of the air processing medium in the freezer as well as of the temperature in the 4 characteristic points in the logs during the experiments was carried out with the help of Data Logger type HygroLog NT3 (*Figure 3 – right*) produced by the Swiss firm ROTRONIC AG (<http://www.rotronic.com>).



*Figure 3. General view of the freezer containing a log (left) and of the Data Logger (right)*

The suggested methodology for the research of the freezing process of poplar (*Populus nigra* L.) logs with diameter of  $D = 0.24\text{ m}$ , length of  $L = 0.48\text{ m}$ , and moisture content above the fiber saturation point was used. Such moisture content allows for the observation of the freezing of both the free and the bound water in the wood during the experiments.

When the logs were completely frozen, they were subjected to defrosting at room temperature. After that, 35 mm-thick disks from the central, undrilled area of the logs were prepared. According to requirements of the standard BDS ISO 3130: 1999, eleven samples with dimensions of 60 x 30 x 35 mm were made (see *Figure 6* below).

The samples were dried at  $103 \pm 2$  °C to estimate their initial moisture content  $u$  and basic wood density  $\rho_b$ , which is equal to the dry mass divided by the green volume. The average values of  $u$  and  $\rho_b$  are needed for experimental results analysis and also to solve, modify and verify the mathematical models of the freezing process of the logs (Deliiski et al. 2014, 2015a). The measured results obtained by the Data Logger during the experiments were additionally processed with the help of a personal computer with an installed licensed software, ROTRONIC HW4.

The very precise instrumentation used during the experiments allowed us to detect the latent heat released by the free water and its impact on the wood freezing process during the crystallization of this water (see below). This phenomenon is not well-known or easily comprehensible, hence it will be explained in detail below.

It is common knowledge that when a given substance is subjected to heating, its internal energy and its temperature increase. However, under certain circumstances, the heat deposited in the system is spent performing work without increasing its temperature. This happens when a phase transformation in the substance occurs.

The phase transformation consists in moving from one aggregate state to another – for example, the passing of ice into water. In those cases, the heat introduced in the substance is transformed into work needed for destruction of the bonds between molecules, which are available in the substance before heat introduction. It is acceptable to term this heat as the latent heat of the phase transformation (Efimov 1985, Pahi 2010).

Therefore, the latent heat is used for description of the thermal energy, which is needed for the change of the aggregate state of a given substance without changing its temperature. When the ice is transformed into water, it is acceptable to term this latent heat as latent heat of fusion and when the water turns into steam it is called latent heat of vaporization. It was found that the latent heat of fusion is equal to  $3.34 \cdot 10^5$  J·kg<sup>-1</sup> and the latent heat of vaporization is about 6.5 times larger and equal to  $2.2572 \cdot 10^6$  J·kg<sup>-1</sup> (Chudinov 1966, 1968, Rivkin – Aleksandrov 1975, Efimov 1985, Spears – Zollman 1990, Pahi 2010).

Ice molecules are connected to one another with significant forces of attraction. The kinetic energy of ice molecules increases during heating, which translates into the increase of their amplitude oscillations. When the melting point of the ice is reached, the amplitude of the oscillations increases so much that separate molecules begin to detach from their places and become free. This process is not accompanied by an increase in ice temperature because of the usage of the latent heat introduced for the overcoming of the intermolecular bonds.

The freezing and melting processes of the water in the wood are reversible.

When the water passes into ice during cooling, it releases latent heat in an amount of  $3.34 \cdot 10^5$  J·kg<sup>-1</sup>. With the help of precise instrumentation, the research and the quantity determination of the impact of the water's latent heat release on the freezing process of the logs are of considerable scientific and practical interest.

### 3 RESULTS AND DISCUSSION

As an example, in *Figure 4* and *Figure 5*, the change in  $t_m$ ,  $\phi_m$ , and  $t$  in 4 characteristic points of two poplar logs with different moisture content  $u = 1.78$  kg·kg<sup>-1</sup> and  $u = 1.04$  kg·kg<sup>-1</sup> (named below as Log 1 and Log 2 respectively) during their 50 h freezing is presented. The record of all data was made automatically by Data Logger with intervals of 15 min.

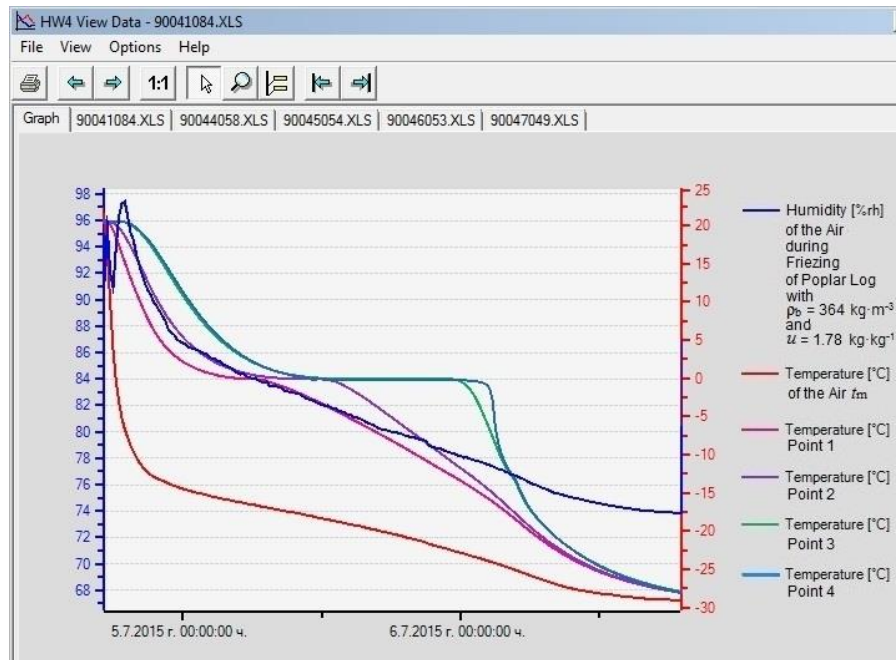


Figure 4. Change in  $t_m$ ,  $\phi_m$ , and  $t$  in 4 characteristic points of poplar Log 1 with  $D = 0.24$  m,  $L = 0.48$  m,  $t_0 = 20.5$  °C,  $\rho_b = 364$  kg·m<sup>-3</sup>, and  $u = 1.78$  kg·kg<sup>-1</sup> during its 50 h freezing from 17:00 on 04.07.2015 to 19:00 on 06.07.2015

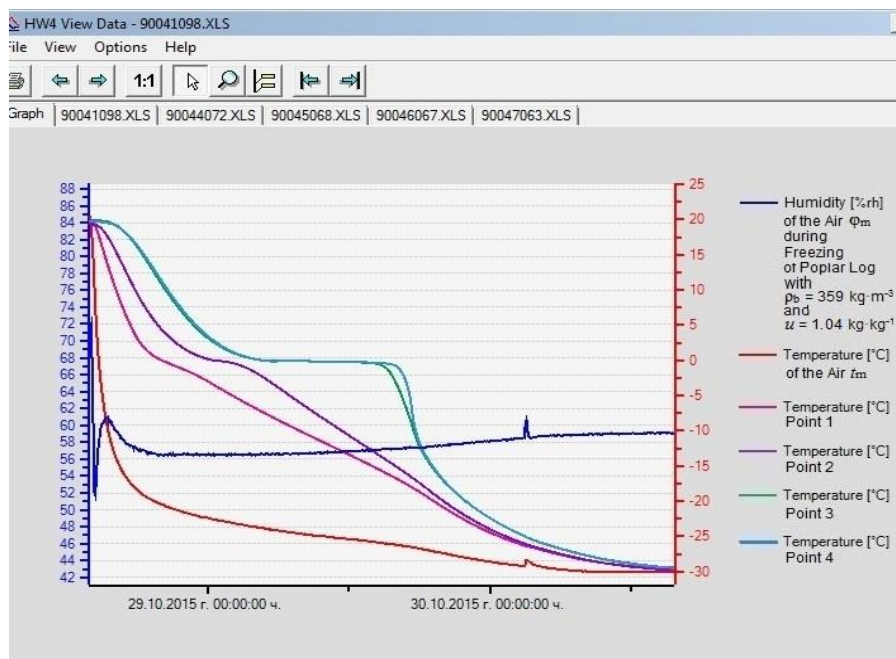


Figure 5. Change in  $t_m$ ,  $\phi_m$ , and  $t$  in 4 characteristic points of poplar Log 2 with  $D = 0.24$  m,  $L = 0.48$  m,  $t_0 = 19.8$  °C,  $\rho_b = 359$  kg·m<sup>-3</sup>, and  $u = 1.04$  kg·kg<sup>-1</sup> during its 50 h freezing from 12:00 on 28.10.2015 to 14:00 on 30.10.2015

In Figure 6 the distribution of the moisture content  $u$  and of the basic density  $\rho_b$  in the cross section of Log 1 is shown.

In Figure 7 and Figure 8 the change in  $t$  of the separate 4 characteristic points of Log 1 in temperature range from 0 °C to -1 °C is shown. The experiments determined that the freezing of the free water in the wood occurs in this range.

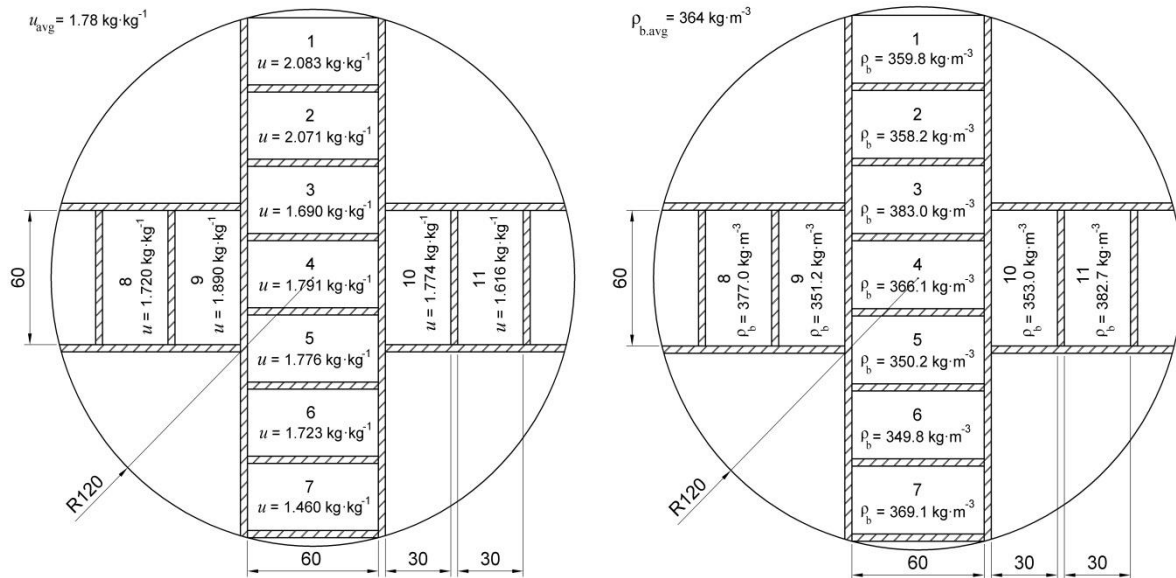


Figure 6. Distribution of  $u$  (left) and  $\rho_b$  (right) in the cross section of Log 1

In Figure 9 and Figure 10 the zoomed change in  $t$  in the characteristic points of Log 1 in the temperature ranges is shown, in which the impact of the release of the latent heat of the free water on the increasing of the wood temperature during log freezing is observed.

On the horizontal and vertical axis of Figure 7 to Figure 10 the astronomic time during the experiments and the temperature in  $^{\circ}\text{C}$  are presented respectively.

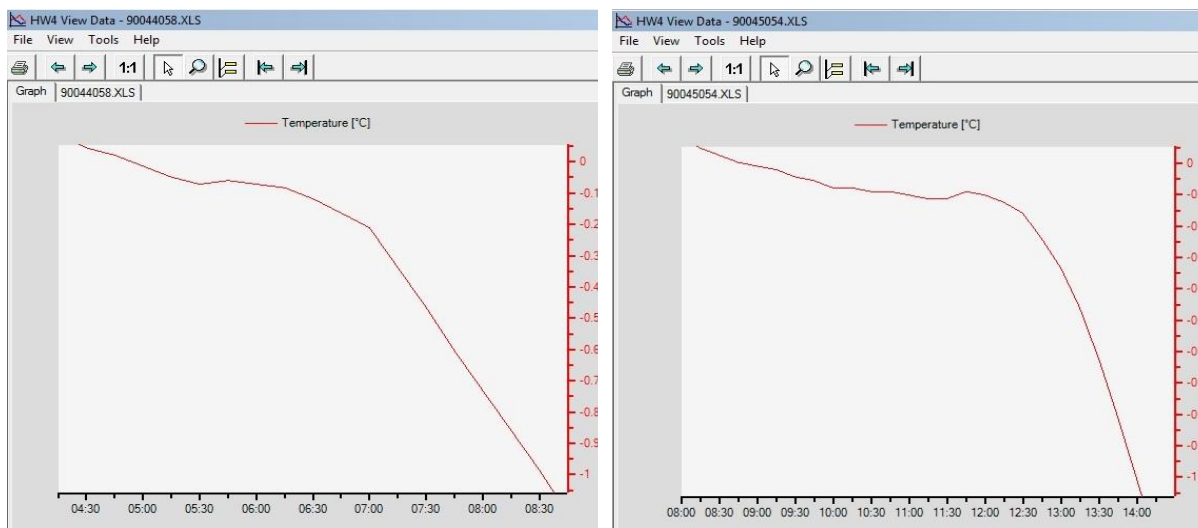


Figure 7. Change in  $t$  in Point 1 (left) and in Point 2 (right) of Log 1 in the range from  $0^{\circ}\text{C}$  to  $-1^{\circ}\text{C}$  during log freezing, depending on time

In Table 1 the duration of the temperature decrease in the characteristic points of Log 1 and Log 2 in the range from  $0^{\circ}\text{C}$  to  $-1^{\circ}\text{C}$  is given (see Figure 7 and Figure 8 for Log 1). This duration is needed for its further comparison to the duration of the defrosting process of the same logs in the temperature range from  $-1^{\circ}\text{C}$  to  $0^{\circ}\text{C}$ .

In Table 2 the temperature ranges and the duration of the impact of the latent heat of the free water in the wood on the change in  $t$  of the characteristic points in Log 1 and Log 2 is illustrated.

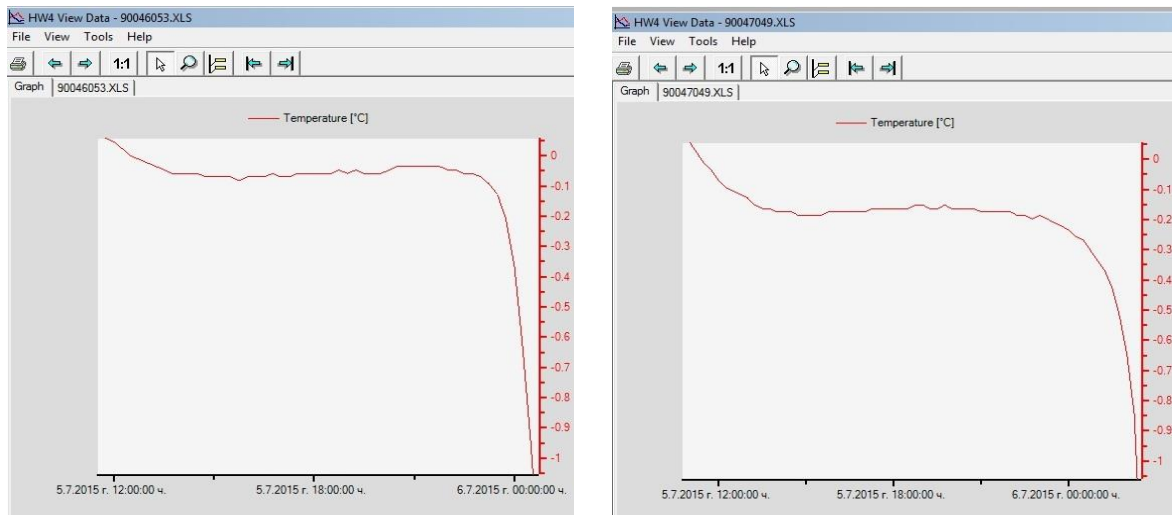


Figure 8. Change in  $t$  in Point 3 (left) and in Point 4 (right) of Log 1 in the range from 0 °C to –1 °C during log freezing, depending on time

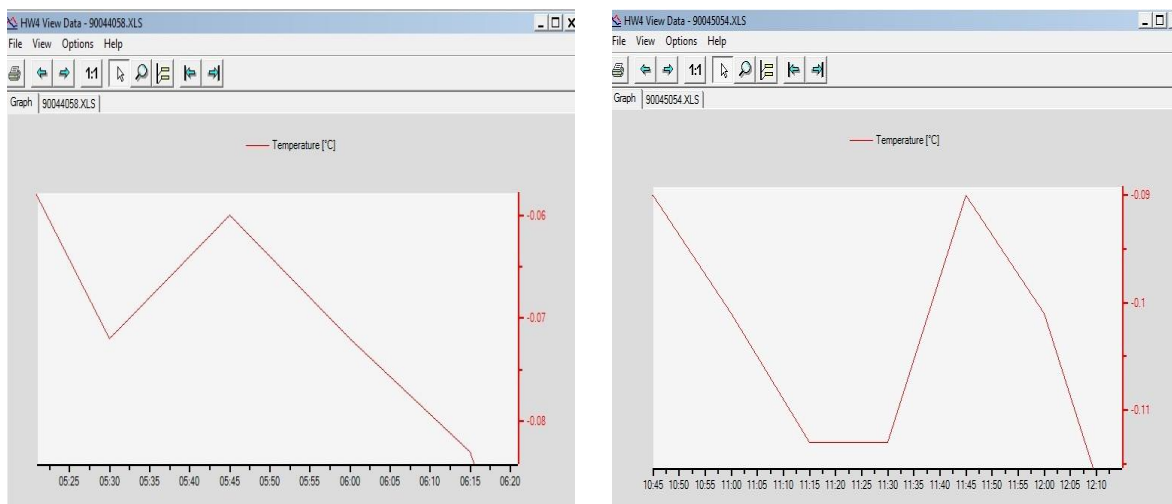


Figure 9. Change in  $t$  in Point 1 (left) and in Point 2 (right) of Log 1 during the impact of the release of the latent heat of the free water on the log freezing process

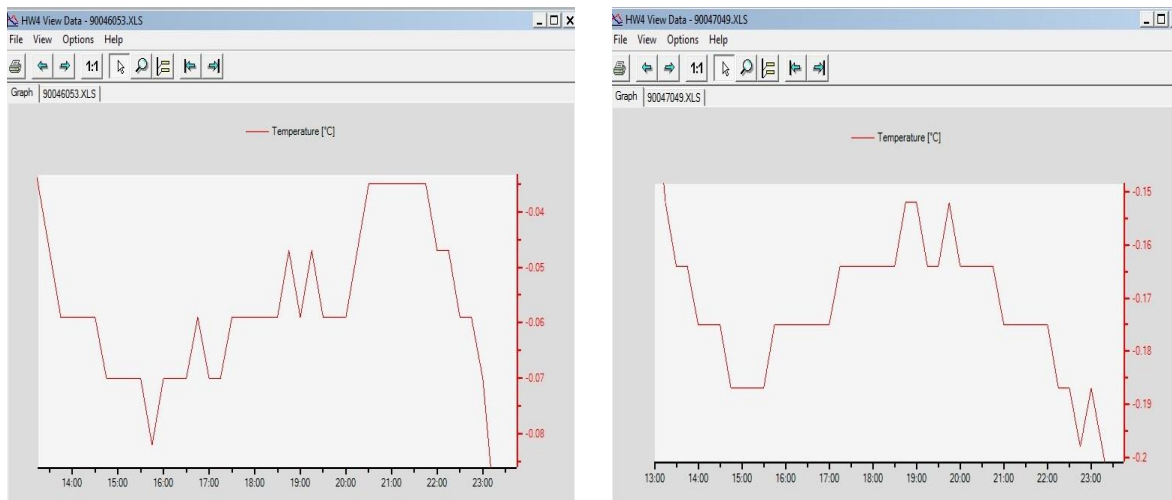


Figure 10. Change in  $t$  in Point 3 (left) and in Point 4 (right) of Log 1 during the impact of the release of the latent heat of the free water on the log freezing process

Table 1. Duration of the decreasing of  $t$  from 0 °C to –1 °C in the characteristic points of poplar logs during their 50 h freezing

| №                                                                                                  | Time of reaching of temperature equal to |                     | Duration of the decreasing<br>of $t$ from 0 °C to –1 °C, h |
|----------------------------------------------------------------------------------------------------|------------------------------------------|---------------------|------------------------------------------------------------|
|                                                                                                    | 0 °C                                     | –1 °C               |                                                            |
| Log 1 with $t_0 = 20.5$ °C, $\rho_b = 364$ kg·m <sup>–3</sup> , and $u = 1.78$ kg·kg <sup>–1</sup> |                                          |                     |                                                            |
| Point 1                                                                                            | 4:54 on 05.07.2015                       | 8:32 on 05.07.2015  | 3.63                                                       |
| Point 2                                                                                            | 8:49 on 05.07.2015                       | 14:00 on 05.07.2015 | 5.18                                                       |
| Point 3                                                                                            | 12:30 on 05.07.2015                      | 0:32 on 06.07.2015  | 12.03                                                      |
| Point 4                                                                                            | 11:24 on 05.07.2015                      | 2:19 on 06.07.2015  | 14.92                                                      |
| Log 2 with $t_0 = 19.8$ °C, $\rho_b = 359$ kg·m <sup>–3</sup> , and $u = 1.04$ kg·kg <sup>–1</sup> |                                          |                     |                                                            |
| Point 1                                                                                            | 20:07 on 28.10.2015                      | 21:34 on 28.10.2015 | 1.45                                                       |
| Point 2                                                                                            | 0:31 on 29.10.2015                       | 3:14 on 29.10.2015  | 2.72                                                       |
| Point 3                                                                                            | 4:45 on 29.10.2015                       | 15:07 on 29.10.2015 | 10.37                                                      |
| Point 4                                                                                            | 4.40 on 29.10.2015                       | 16:10 on 29.10.2015 | 11.50                                                      |

Table 2. Duration  $\tau_{LH}$  and temperature difference  $\Delta t_{LH}$  of the impact of the latent heat (LH) of the free water on the increasing of the wood temperature in the characteristic points of poplar logs during their 50 h freezing

| №                                                                                                  | Time and wood temperature at the beginning and ending of the impact of LH on the wood freezing |                     | Maximal wood temperature and time of its reaching under impact of LH on the wood freezing |       | $\tau_{LH}$ , h | $\Delta t_{LH}$ , °C |
|----------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|---------------------|-------------------------------------------------------------------------------------------|-------|-----------------|----------------------|
|                                                                                                    | Time                                                                                           | $t_{LH}^{beg}$ , °C | $t_{LH}^{max}$ , °C                                                                       | Time  |                 |                      |
| Log 1 with $t_0 = 20.5$ °C, $\rho_b = 364$ kg·m <sup>-3</sup> , and $u = 1.78$ kg·kg <sup>-1</sup> |                                                                                                |                     |                                                                                           |       |                 |                      |
| Point 1                                                                                            | 5:30 and 6:00                                                                                  | -0.072              | -0.060                                                                                    | 5:45  | 0.50            | 0.012                |
| Point 2                                                                                            | 11:15 and 12:07                                                                                | -0.113              | -0.090                                                                                    | 11:45 | 0.87            | 0.023                |
| Point 3                                                                                            | 15:45 and 22:45                                                                                | -0.082              | -0.035                                                                                    | 20:30 | 7.00            | 0.047                |
| Point 4                                                                                            | 14:45 and 23:00                                                                                | -0.187              | -0.152                                                                                    | 18:45 | 8.25            | 0.035                |
| Log 2 with $t_0 = 19.8$ °C, $\rho_b = 359$ kg·m <sup>-3</sup> , and $u = 1.04$ kg·kg <sup>-1</sup> |                                                                                                |                     |                                                                                           |       |                 |                      |
| Point 1                                                                                            | 20:15 and 20:30                                                                                | -0.120              | -0.120                                                                                    | 20:15 | 0.25            | 0.093                |
| Point 2                                                                                            | 1:10 and 1:30                                                                                  | -0.110              | -0.110                                                                                    | 1:10  | 0.33            | 0.070                |
| Point 3                                                                                            | 5:05 and 7:24                                                                                  | -0.059              | -0.001                                                                                    | 5:30  | 2.32            | 0.058                |
| Point 4                                                                                            | 5:40 and 10:20                                                                                 | -0.164              | -0.036                                                                                    | 6:15  | 4.70            | 0.128                |

The experimental results presented above, and also the results from our research of the freezing process of logs from some wood species (poplar, beech, pine, and spruce) at different moisture contents, show that the free water in the wood freezes in the temperature range between 0 °C and –1 °C. This fact did not prove the points of view of Chudinov (1966, 1968) and Topgaard – Söderman (2002), which have been presented in Deliiski et al. (2015c). According to these scientists, if the wood has a significant quantity of free water, i.e. if the cell holes and the gaps among the cells are almost completely filled with water (such a condition was fulfilled in our experiments presented above), the centers of crystallization during cooling arise in the water at temperatures around –5 °C ÷ –6 °C. According to the same authors, if the wood moisture content is slightly larger than the fiber saturation point, i.e. a small quantity of free water is present in the wood, then the centers of crystallization in it arise even at temperatures around –12 °C ÷ –15 °C.

The analysis of the obtained results about the freezing process of the studied logs showed the following:

- The temperature decrease of the processing air medium  $t_m$  in the freezer goes on exponentially at the beginning of the freezing process of the logs and, after that, gradually passes into an almost straight line (*Figure 4 and Figure 5*).
- The change of the humidity of the processing air medium  $\phi_m$  in the freezer goes on according to a complex curve. At the beginning of the freezing process it jumps up to 97% at Log 1 (*Figure 4*) and up to 73% at Log 2 (*Figure 5*), but after that it gradually decreases smoothly and reaches a value of 74% (Log 1) and of 59% (Log 2) at the end of the 50 h logs' freezing.
- The non-stationary decreasing of the temperature in the logs' characteristic points goes on according to very complex curves during the freezing process (*Figure 4 and Figure 5*).
- While the water in the log is fully in a liquid state, the decreasing of  $t_m$  causes a smooth decreasing of  $t$  in the characteristic points. The smoothness of the decreasing of  $t$  depends proportionally on the distance of the points from both logs' surfaces.
- Specific, almost horizontal sections of temperature retention for a long period of time in the range from 0 °C to –1 °C can be seen, while in the points a complete freezing of the free water in the wood occurs (*Figure 7 and Figure 8*). How far the point is distanced from the logs' surfaces and the larger the amount of the free water in the wood determines how much these sections with temperature retention are extended, as follows (*Table 1*):
  - in Point 1: 3.63 h for Log 1 and 1.45 h for Log 2;
  - in Point 2: 5.18 h for Log 1 and 2.72 h for Log 2;
  - in Point 3: 12.03 h for Log 1 and 10.37 h for Log 2;
  - in Point 4: 14.92 h for Log 1 and 11.50 h for Log 2.

The reason of such a long retention of wood temperature is the very low temperature conductivity of the wood during freezing of the free water in it (Deliiski et al. 2015b). It is seen in *Table 1* that the temperature  $t$  in Point 4, which is the most distanced from the logs' surfaces, reaches a value of 0 °C earlier than  $t$  in Point 3 during the initial cooling of logs before their subsequent freezing. This apparent anomaly can be explained by the influence of the smaller moisture content  $u$  of the bottom part of the logs (in comparison with the moisture content of their upper parts) on the wood temperature conductivity,  $a$ . For example, the average value of  $u$  for the bottom layers 5, 6, and 7 of Log 1 (*Figure 6 – left*) is equal to 1.653 kg·kg<sup>-1</sup>; however, the average value of  $u$  for the upper layers 1, 2, and 3 is equal to 1.948 kg·kg<sup>-1</sup> i.e. it is larger by about 18%.

The coordinates of Point 3 determine that the change of  $t$  in this point depends on the heat transfer only through the upper log's layers (*Figure 1 – right and Figure 2*), but the change in  $t$  of central log's Point 4 depends on the heat transfer through all the log's layers.

It is well known that the decrease in  $u$  of the non-frozen wood causes an increase in its temperature conductivity  $a$  (Chudinov 1966, 1968, Shubin 1990, Požgaj et al. 1997, Trebula – Klement 2002, Videlov 2003, Deliiski 2013b, Deliiski et al. 2015b). In our case, this means that the lower moisture content of the bottom logs' layers causes an accelerated heat transfer in radial direction to Point 4 in comparison to the heat transfer to Point 3. As a consequence, the temperature of 0 °C is reached earlier in Point 4 than in Point 3 during the log's cooling, which is an initial part of the logs' freezing process. The difference between the average moisture contents of the bottom and upper (wetter) layers of Log 2 is significantly less than of Log 1. That is why reaching 0 °C in Point 4 of Log 2 occurs only 5 min earlier than in Point 3 while Point 4 of Log 1 reaches 0 °C 60 min earlier than Point 3 (refer to *Table 1*).

- During the freezing of the free water in the log, specific sections of insignificant increases in wood temperature arise (Figure 9 and Figure 10). The reason for this is the impact of the latent heat of the free water, which is released during water crystallization and causes the warming up of the wood (Efimov 1985, Spears – Zollman 1990, Pahi 2010). The increase of the wood temperature,  $\Delta t_{LH}$ , which is caused by the released latent heat, for poplar Log 1 with moisture content  $u = 1.78 \text{ kg} \cdot \text{kg}^{-1}$  was measured to be equal between  $0.012 \text{ }^{\circ}\text{C}$  and  $0.047 \text{ }^{\circ}\text{C}$ . The duration of the warming up of the wood because of the latent heat release,  $\tau_{LH}$ , was equal to 0.50 h for Point 1; 0.87 h for Point 2; 7.00 h for Point 3 and 8.25 h for Point 4 (Table 2).

Analogously, the temperature increase  $\Delta t_{LH}$  for poplar Log 2 with lower moisture content  $u = 1.04 \text{ kg} \cdot \text{kg}^{-1}$  was measured to be equal between  $0.058 \text{ }^{\circ}\text{C}$  and  $0.128 \text{ }^{\circ}\text{C}$ . The duration  $\tau_{LH}$  for this log was equal to 0.25 h for Point 1; 0.33 h for Point 2; 2.32 h for Point 3, and 4.70 h for Point 4.

It can be noted that if the temperature data recording by Data Logger had been performed with intervals shorter than 15 min, the maximum wood temperature,  $t_{LH}^{\max}$ , and time of its reaching under impact of LH on wood freezing would be different than these given in Table 2; thus, the values of  $\Delta t_{LH}$  for Log 1 probably would be larger than the values of  $\Delta t_{LH}$  for Log 2.

- After the whole amount of free water in the separate characteristic point freezes, the bound water in the wood starts to freeze. The decreasing of  $t$  in all points during the freezing of the bound water is smoother than the decreasing of  $t$  during the cooling of the logs before the starting of the water crystallization in the wood.

When the 50 h freezing process ends, the temperature of all characteristic points of Log 1 and Log 2 reach a value equal to  $-27.9 \pm 0.2 \text{ }^{\circ}\text{C}$  and  $-29.6 \pm 0.1 \text{ }^{\circ}\text{C}$  respectively. Then the temperature  $t_m$  is equal to  $-29.1 \text{ }^{\circ}\text{C}$  and  $-30.1 \text{ }^{\circ}\text{C}$  respectively (see Figure 4 and Figure 5).

#### 4 CONCLUSIONS

This paper describes a methodology for experimental research of the freezing process of logs. It also presents the first results from the usage of the suggested methodology for measurement of the change in the temperature and humidity of the processing medium,  $t_m$  and  $\varphi_m$ , respectively, and also in the non-stationary temperature distribution in 4 characteristic points of the longitudinal section of poplar logs during their 50 hours freezing in a freezer with an adjustable temperature range from  $-1 \text{ }^{\circ}\text{C}$  to  $-30 \text{ }^{\circ}\text{C}$ .

The precise instrumentation allowed, for the first time ever, the measuring of the impact the latent heat released by the free water on the log had on the warming up of the wood during water crystallization in the logs. The increase of the wood temperature caused by the released latent heat, for the studied poplar logs with moisture content  $u = 1.78 \text{ kg} \cdot \text{kg}^{-1}$  (Log 1) and  $u = 1.04 \text{ kg} \cdot \text{kg}^{-1}$  (Log 2) was measured to be equal between  $0.012 \text{ }^{\circ}\text{C}$  and  $0.047 \text{ }^{\circ}\text{C}$  for Log 1 and between  $0.058 \text{ }^{\circ}\text{C}$  and  $0.128 \text{ }^{\circ}\text{C}$  for Log 2. The impact of the latent heat release on the wood's warming up lasts from 0.50 h in the peripheral layers of the Log 1 to 8.25 h in the log's center and from 0.25 h to 4.70 h for Log 2.

It can be noted that in the accessible specialized literature, there is no information at all about the impact of the release of the latent heat on the wood freezing process.

Our experimental results show that the free water in the wood freezes in a temperature range between  $0 \text{ }^{\circ}\text{C}$  and  $-1 \text{ }^{\circ}\text{C}$ . This fact did not prove the points of view of some of the above mentioned authors who claim the free water in the wood freezes at much lower temperatures.

Our results prove the popular belief that after the whole amount of free water freezes, the freezing of the bound water in the wood starts and that it takes place gradually during the rest time of the experiments.

The obtained experimental results will be used for the modification and verification of our 1D and 2D mathematical models of the freezing process of logs (Deliiski et al. 2014, 2015a). They could be very useful for the creation, solution, and verification of analogous models by other researchers.

The methodology suggested in this work could be used for experimental research of the freezing processes of different capillary-porous bodies. For example, for winter research concerning the impact of free water in live trees or in fresh concrete regarding freezing along the radius or the thickness at different ambient temperatures, etc.

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## The Hungarian Wood-Based Panel Industry and its Impact on the Environment

Gábor LABORCZY\* – András WINKLER

Institute of Wood and Paper Technology, Simonyi Károly Faculty of Engineering, Wood Sciences and Applied Arts,  
University of West-Hungary, Sopron, Hungary

**Abstract** – It is well known that worldwide deforestation has a negative impact on the global environment. Forests play an important role in producing oxygen as well as retaining gases that create the greenhouse effect. Forests primarily absorb carbon dioxide, the major air pollutant released by the industrial activities. Energy production is the major source of environmental contamination. In addition to reducing CO<sub>2</sub> emissions, another issue this industrial sector must tackle is to decrease the use of fossil fuels by substituting them with renewable, environmentally friendly energy sources. One of the answers to these challenges is the utilization of biomass as energy sources. However, biomass-based fuels include short bolts, split round-wood, pulpwood, bark and by-products of sawmilling, which are the raw materials for the wood-based panel industry as well. Wood utilization of the forest products industry has a major impact on the delayed release of carbon dioxide stored in the wood. All over the world, just as in Hungary, the wood-based panel industry mainly uses low quality wood resources and turns them into value added products. The elongation of the life cycle of low quality wood materials decreases CO<sub>2</sub> emissions, thus significantly contributing to environmental protection. Furthermore, it is assumed that raw material demand of the wood-based panel industry could be satisfied by focusing on sustainable forest management and well-planned reforestation. Additionally, special energy-plantations may provide extra wood resources, while waste and other non-usable parts of trees contribute to the effective and economic operation of biomass utilizing power-plants.

This paper summarizes the current situation of the Hungarian wood-based panel industry and discusses the effects of the panel manufacturing processes on the environment. Also, it outlines the possible future of this important segment of the forest products industry.

**wood-based panel industry / raw material production / biomass utilization / forests for energy production / short rotation plantations / carbon dioxide emission / forest management**

**Kivonat** – A magyar falemezipar jelenlegi helyzete és környezeti hatásai. A természeti környezet és ezen belül az erdőterületek további rombolása visszafordíthatatlan káros következményekkel jár. Az erdő egyik fontos szerepe az éltető oxigén termelése és az üvegházhatású gázok, különösen a légkörben lévő széndioxid megkötése. A környezeti terhelés egyik legjelentősebb tényezője az energia előállítás. E téren a kibocsátott széndioxid mennyiségének csökkentésén túl jelentős kérdés a fosszilis energiahordozók felhasználásának kiváltása az újratermelhető környezetbarát tüzelőanyagra átváltított biomassza erőművekkel. Ezeknek az erőműveknek az egyik meghatározó alapanyagai az ilyen módon hasznosított faanyagok, melybe beletartoznak a falemezipar alapanyagbázisát jelentő sarangolt ipari választékok és erdei aprítékok is, rosszabb esetben az erdőgazdaság által kitermelt bármely ipari célra

\* Corresponding author: lgabi2008@gmail.com; H-9400 SOPRON, Bajcsy-Zs. u. 4., Hungary

egyébként még hasznosítható faanyag is. A fában megkötött szén-dioxid minél későbbi felszabadításában a fafeldolgozásnak és a fahasználatnak fontos szerepe van. A legsokoldalúbban gyengébb minőségű faanyagot hasznosító iparág a Magyarországon is nagy múltra visszatekintő falemezipar. Az iparág a faipar egyik meghatározó ágazata. A hazai erdőgazdálkodás fenntarthatóságot szem előtt tartó tervszerű fejlesztésével megoldható a falemezipar számára megfelelő minőségű és mennyiségű alapanyag biztosítása, valamint energetikai ütevények telepítésével, a felhasznált faanyag összegyűjtésével, a keletkezett hulladékok és az ipari célra már nem alkalmazható faanyag felhasználásával a biomaszra erőművek hatékony és gazdaságos működtetése is.

**lemezipar / falemezipari alapanyag-termelés / biomasz hasznosítás / energiaerdők / szén-dioxid kibocsátás / erdőgazdálkodás / falemezipar jövőképe**

## 1 INTRODUCTION

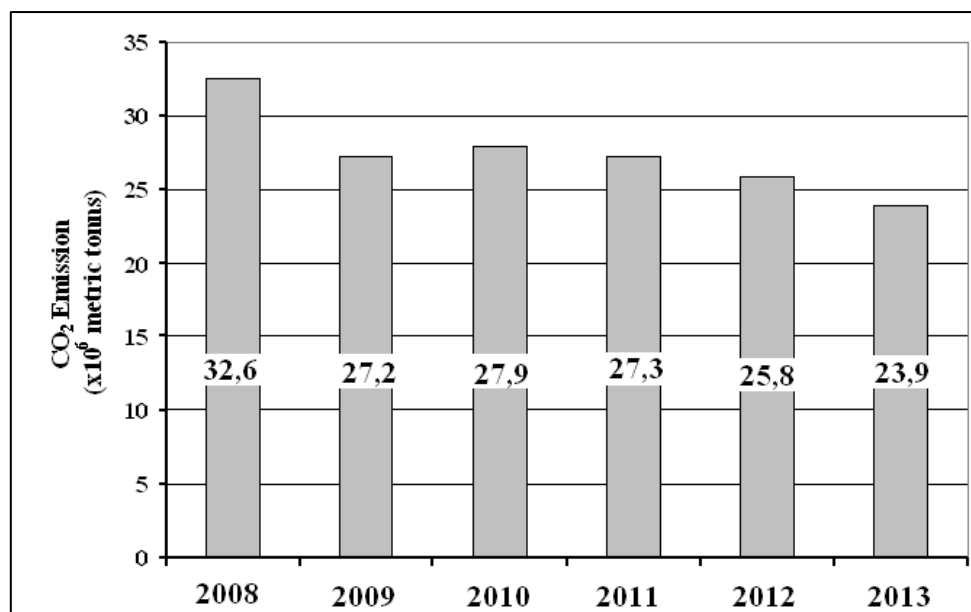
Forests are important habitats that are home to diverse forms of life that are governed by the law of nature and human interference. Over the past several decades societies have recognized that further destruction of the natural environment, including deforestation, has a catastrophic effect on the well-being of human life. Two important roles of forests are oxygen generation and the carbon dioxide retention (Shmulsky et al. 2011). For the latter, wood products manufacturing and utilization are key factors in retaining the stored CO<sub>2</sub> by delaying natural decay and burning (Nieder et al. 2008). Due to the intense harvesting of trees over the last thirty-year period, the Earth's forested areas has decreased by an area the size of Hungary (~ 90.000 km<sup>2</sup>) annually (Molnár 2005; Barbu 2011). To stop or reverse this trend, a new philosophy suggested decreasing the volume of harvesting and substituting solid wood with synthetic or man-made materials. This practice resulted in the intensive use of metals, synthetic polymers, reinforced concrete, and other types of construction materials. However, the comparison of energy consumption to produce these construction materials shows unfavourable characteristics. If we take the 580 kWh energy required to produce one metric ton of solid construction wood as unity, then the equivalent energy necessary to produce one ton of brick, cement, plastic, glass, steel and aluminium takes 4, 5, 6, 14, 24, and 126 units, respectively (Molnár – Börcsök 2011). Additionally, if we consider the environmental pollutants emitted by the manufacturing processes of these man-made construction materials, the negative impact on the environment is quite clear. In Hungary the only source of renewable material is the forest. Furthermore, timber production requires less energy and can be utilized without generating harmful wastes. Consequently, it is the interest of any society to manufacture products made of wood and that it should be using these wooden products for as long as it is possible (Hoadley 2000).

An excellent example of wood usage in construction is the lookout tower of Pyramiden summit built in 2013 near Klagenfurt at Worth Lake. The 100 m high superstructure is currently the highest wooden structure in the world. Regional timber sources certified by the PEFC were used to erect the tower (Pyramidenkogel 2013).

In Hungary the consumption of wood products (round-wood equivalent) is about 0.7 m<sup>3</sup> annually per person. This figure corresponds to the overall world average, though it is lagging behind the consumption of 1–1.2 m<sup>3</sup> per year reported by more developed countries (Molnár 2011).

## 2 HUNGARY'S CARBON DIOXIDE EMISSIONS

According to the report of the European Council issued in April 2, 2013, the 200 Hungarian manufacturing companies participating in the European Union's CO<sub>2</sub> regulations (EU ETS) released 21 million tons of CO<sub>2</sub> into the atmosphere in 2012 (*Figure 1*). This means a more than 6% decrease in CO<sub>2</sub> emissions compared to the year 2011. The average emissions of the 27 EU countries shows 1.4% decrease during the same period. While countries like Great Britain and France had increased emissions, Germany stayed on the same level. Poland and Italy decreased their CO<sub>2</sub> emissions, but by fewer percentage than Hungary did. It should be noted, however, that the decrease in Hungarian emissions is mainly caused by a decrease in industrial production, rather than energy efficiency initiatives in manufacturing processes.



*Figure 1. Hungarian industrial carbon dioxide emissions*  
(Source: KSH STADAT 2015)

According to section 3.3 of the Kyoto Agreement report, since 1990 forest operations (including natural growth, plantations and harvesting) have resulted in 1.26 million tons of net CO<sub>2</sub> absorption. Furthermore, section 3.4 of this report states that other forest management practices resulted in an additional 1.68 million net tons of carbon retention. To adhere to the regulations of the Kyoto Agreement, control of gas emissions that generate the greenhouse effect, is necessary. This can be achieved efficiently by the plantation of new forests (NÉBIH 2012).

## 3 THE PATHWAY OF WOOD-STORED CARBON DIOXIDE UNTIL RE-EMISSION

Like other plants, trees produce organic materials, absorb water from the soil, capture carbon dioxide from the atmosphere, and release oxygen through photosynthesis. Then, through the transformation of natural sugars, trees build up their different organic compounds. The stored CO<sub>2</sub> in the woody tissues is released during natural decomposition of the material or by incineration (Hinckley et al. 2011). Carbon dioxide emissions are a major cause of the greenhouse effect. Therefore, elongated CO<sub>2</sub> retention is a crucial factor regarding climate change. It is a common interest to keep the stored CO<sub>2</sub> within the woody tissues for as long as possible (Batjes 1999). In this context, the wood-based panel industry has important functions; as represented by the explanatory diagram on *Figure 2*.

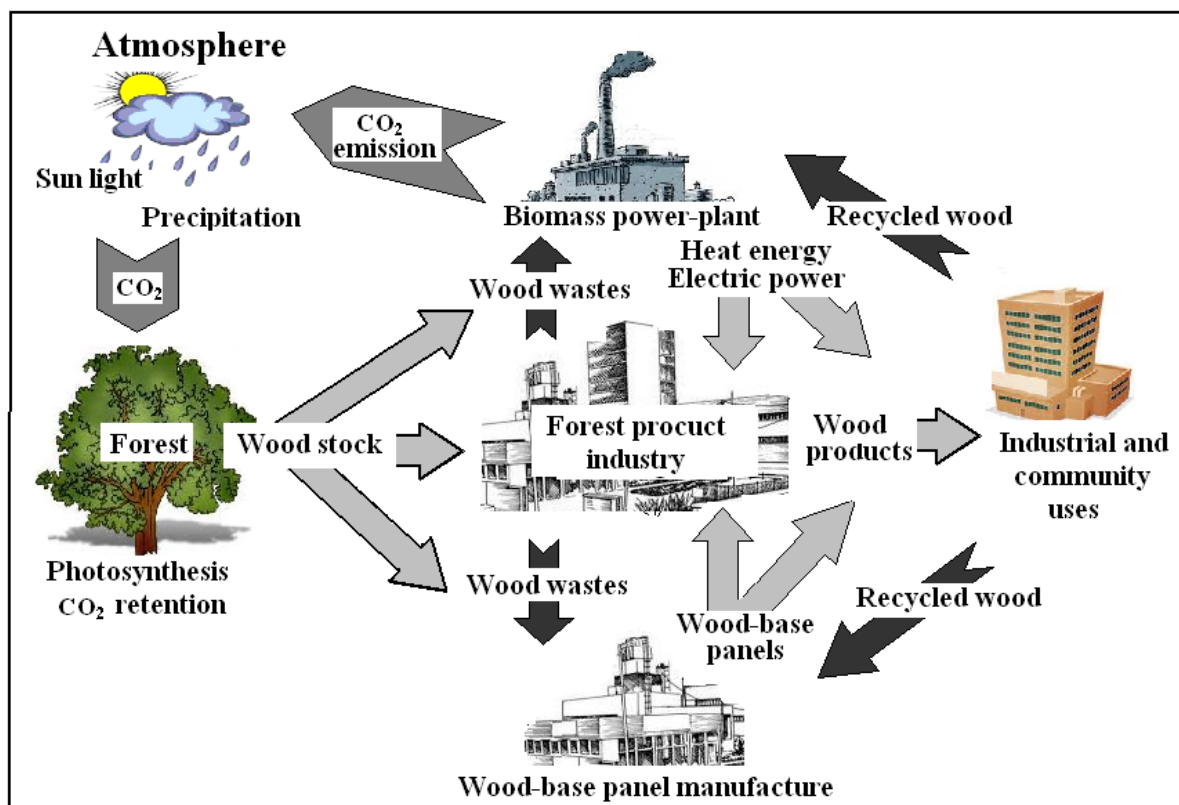


Figure 2. The cycle of carbon dioxide stored in wood. (Source: own construction)

The wood processing industry uses different kinds of solid wood materials harvested from forests. These raw materials contain stored CO<sub>2</sub>, and when in the form of different commodities or products, ensure the retention of carbon for a longer period of time.

The other form of utilization of forest resources is energy production. Firewood, forest residuals, and industrial wastes or residuals like bark, wood slabs, etc., are burned to generate heat or electrical energy (Sdrjevic 2007). The forest products industry generally uses its own residues as a supplemental energy source. However, the drawback of this practice is that the stored carbon is immediately released into the atmosphere in the form of CO<sub>2</sub>.

The most favourable wood utilization, in view of the carbon cycle, includes the use of wood that is below industrial grade, the incorporation of wastes from other wood processing technologies, and the reuse of former structural wood products (recycled wood) in the wood-based panel manufacturing processes. Thus, the immediate CO<sub>2</sub> emission is eliminated, value-added products are produced in the construction and furniture industries, and long-term carbon storage in wood is ensured.

If we want to emphasize the positive role of wood products in climate protection, then the forest products industry should be run on continuous positive carbon retention. The civilization carbon cycle<sup>1</sup> of wood products is continuously positive if the carbon entering the system is less than the carbon being released or less release than carbon intake occurs (Schöberl 2012). This requires that wood products remain continuously in the civilization carbon cycle for an increased period of time. This may be achieved by the utilization of recycled wood in the wood-based panel industry and decreasing the volume of incinerated wood. However, achieving these goals makes the involvement of judicial and economical regulations necessary.

<sup>1</sup> civilization carbon cycle: the flow of carbon, stored in wood products, caused by human activities

European Parliament and Council renewable energy source utilization directives require that Hungary produce a minimum of 13% of its overall energy consumption from renewable energy sources by the year of 2020 (USZT 2010a).

In addition to CO<sub>2</sub> emissions, another issue is replacing fossil energy carriers with renewable alternatives. Biomass combustion energy plants use environmental friendly fuels that originate mostly from renewable sources (Scurlock et al. 1993). Biomass primarily originating from agriculture and forestry are used to generate heat energy through burning. Other renewable energy sources include biogas, biodiesel fuels, as well as geothermal, solar, wind and hydro energies. In Hungary, 80% of energy currently produced with renewable sources comes from biomass, with about 50% of this volume being wood (USZT 2010b). This amount includes wood resources that may be used for wood-based panel manufacturing, such as short bolts, split round-wood, forest residues, and other types of harvested trees that are still utilized by industry.

Environmental protection is an additional concern that runs parallel with the energy problem. Changing climate conditions require particularly close attention. Hungary volunteered to increase its energy consumption from renewable sources by 14.65% by the year of 2020. This goal can only be achieved if the country produces approximately 3-3.5 million tons of solid biomass annually for the purpose of generating electricity. This biomass volume is equivalent to 7–10% of the country's imported natural gas. According to another study, 10-12 million tons of biomass are needed altogether to achieve the objectives of this energy plan (Lontay 2011). Considering the current yield of fire wood harvesting, the volume of by-products and other waste materials, it is forecasted that at least 100,000 ha new energy-wood plantations would have to be created to satisfy this increased demand. Also, all biomass production should be done by sustainable forest and agricultural operations.

There is great potential to produce biomass on plots released from traditional agricultural cultivations. These areas are possible growing sites for new energy-wood plantations and other types of energy-plants. Biomass production in Hungary shows encouraging features. Within this, based on the traditional forest managements and operations, dendromass production for energy use is particularly feasible.

On the other hand, the extensive establishment of biomass operated energy plants may cause wood shortages that impact the wood processing industry in the region. (De Cock 1999). A typical example of this situation occurred in Austria during the Klagenfurt biomass energy plant project realization where 150 wood processing manufacturers in Carinthia requested guarantees that their wood supply would not be affected by the biomass energy plant that required 300,000 m<sup>3</sup>/ of fuel wood per year in order to operate. Prognoses revealed that there would be a round-wood deficiency of about 3 million m<sup>3</sup> in Carinthia by the year of 2020. Between 2003 and 2011, the prices for energy-wood increased by 50% and further increases in fuel wood prices are expected (Klagenfurti Biomassza Erőmű 2013).

### **Further opportunities in environmental protection for the wood-based panel industry**

Wood-based panel production, like all industries using wood, place pressure on a resource that is vital to oxygen creation and environmental protection.

In the quota calculation method introduced in the new section of the Kyoto convention, the quantity of wood-based panel products containing stored carbon of a given year has already been included in the quantity of stored carbon prescribed for the country (Király – Kottek 2013). Therefore, wood-based panel production has become more important in this aspect as the country may obtain considerable additional income from the sale of its unused quotas.

Further environmental protection may be achieved through the marketing of Hungarian wood material and wooden products to familiarize consumers with the beneficial characteristics of wood products; this would also help fortify environmentally friendliness in product choice.

#### 4 THE HUNGARIAN WOOD-BASED PANEL INDUSTRY

##### The current situation of wood-based panel manufacturers

The economic recession had a serious impact on the Hungarian forest products industry. Since 2005, production volume and net revenue generation show ups and downs, but on average the trend is decreasing. First, the volume of production decreased by 10%; then in 2008, there was a significant increase (22.1%) compared to the production volume before 2005. The largest drop in production (29%) occurred in the following year due to the recession in West Europe. Domestic and export sales dropped by 24 and 40%, respectively. In recent years the demand for export wood products increased by 25.7%, while domestic sales rose only slightly. Since then, production and revenue generation of the forest products industry shows decreasing trends; however, the severity is not so pronounced (FAOSTAT 2005–2015).

Due to changing market and economic circumstances, revenue generation varies year-by-year for important segments of the forest products industry. In 2000, wood-based panel manufacturing was second, with 29.5% share of the total revenue generated by the industry; while construction joinery manufacturing was the first (37%). Based on sales data obtained during the first half of the year 2012, construction joinery product manufacturing preserved its top position, although its overall share decreased (33.4%), while lumber production took the second place (24.6%), and wood-based panel manufacturing dropped to third (23.2%). Despite the drop in the production of important wood products, the import of such commodities is still significant.

Generally, the volume of production is governed by the demand. The decreased raw material need of the largest customers (construction and furniture industries) decreased the demand for wood-based panels. Diagrams in *Figure 3* clearly indicate this trend for a five-year period. The main reason for the drops in production is the closure of manufacturing facilities like the INTERSPAN particleboard plant at Vásárosnamény. The closing of domestic manufacturing facilities triggered some increase in the import of wood base-panels within these weak market circumstances.

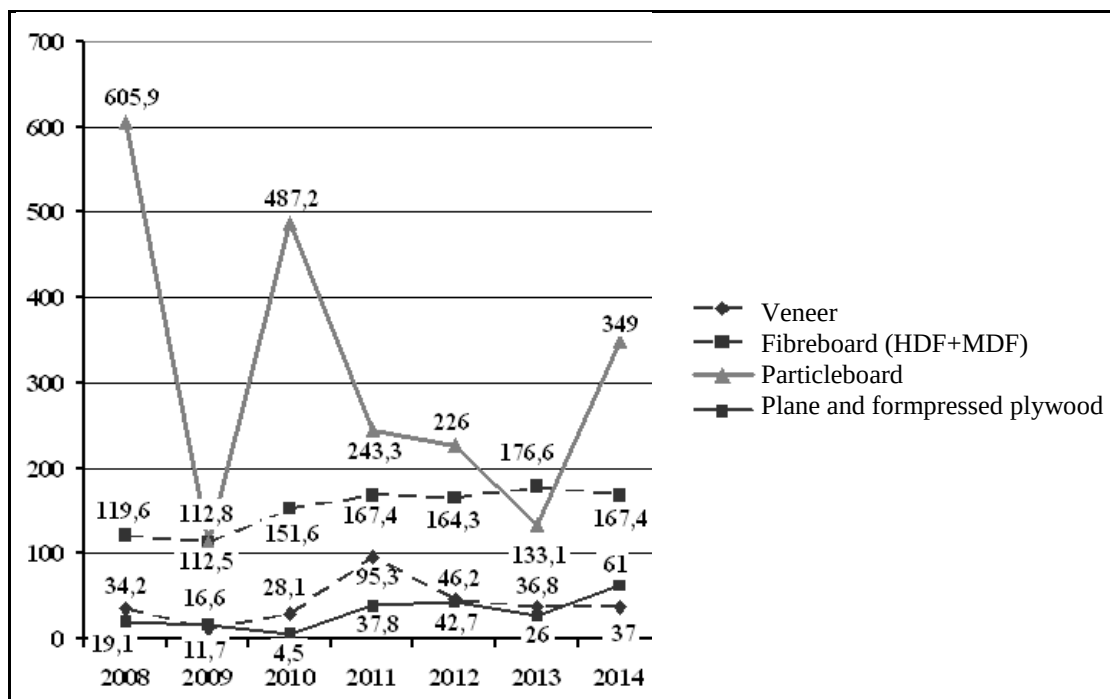


Figure 3. The annual production volume of selected wood-based panel products.  
Oy: Production volume ( $\times 10^3 \text{ m}^3$ ); Ox: Years Surveyed (Source: FAOSTAT data bases 2015)

Despite the decrease in wood-based panel production, production began increasing again in recent years (*Table 1*). For the same period, the foreign trade balance of wood products is compiled in *Table 2*. The substantial negative balance of sawmill products is due to the mill closures that caused increased imports of softwood and hardwood lumber and timber. For the revitalized domestic sawmill industry and for the structural composite manufacturers, this means a possible market area.

*Table 1. Production volume of selected wood products ( $\times 10^3 \text{ m}^3$ )*

| Wood Products                  | 2008  | 2009  | 2010  | 2011  | 2012  | 2013  | 2014  |
|--------------------------------|-------|-------|-------|-------|-------|-------|-------|
| Particleboard                  | 605.9 | 112.8 | 487.2 | 243.3 | 226   | 133.1 | 349   |
| Fibreboard (HDF+MDF)           | 119.6 | 112.5 | 151.6 | 167.4 | 164.3 | 176.6 | 167.4 |
| Veneer                         | 34.2  | 11.7  | 28.1  | 95.3  | 46.2  | 36.8  | 37    |
| Plane and form pressed plywood | 19.1  | 16.6  | 4.5   | 37.8  | 42.7  | 26    | 61    |

(Source: FAOSTAT data bases 2015)

*Table 2. Foreign trade balance of wood products ( $\times 10^3 \text{ m}^3$ )*

| Wood products     | 2008 | 2009 | 2010 | 2011 | 2012 | 2013   |
|-------------------|------|------|------|------|------|--------|
| Round-wood        | 537  | 628  | 610  | 832  | 922  | 13,012 |
| Sawn wood         | -223 | -364 | -251 | -246 | -81  | -140   |
| Wood-based panels | 51   | -64  | 19   | 4    | -149 | -148   |

(Source: FAOSTAT data bases 2015)

The overall European economic recession affected all sectors of the forest products industry and destabilized them financially. Thus, the biggest consumers of panel products, the furniture and construction industries, were also distressed. Furthermore, the raw material producing forest management enterprises were also indirectly negatively motivated.

## 5 DEVELOPMENT OF MANUFACTURING FACILITIES

Hungary had a great tradition of wood-based panel manufacturing, but through the privatization of state owned enterprises, several smaller plants ceased to exist, while the larger facilities were soon acquired by foreign companies. Nevertheless, these mergers did not automatically mean survival. A typical example of such a situation occurred in 2011 when Interspan Kft. in Vásárosnamény was shut down by the Swiss KronoGroup. The owner could not see guarantees for the return of investments totalling about 15-20 billion HUF that was needed to update the entire manufacturing technology (HVG 2010). Instead, a new OSB plant is being built at the same location and it is expected to begin operations in 2016.

For several other Hungarian companies, merging with foreign enterprises meant not only survival, but prosperity as well:

- In 1994 the available wood-based panel manufacturing capacity triggered the formation of Derula Manufacturing and Trade Co. The Italian affiliated manufacturing facility is operating in Szolnok, in Central Hungary (Derula 2013).
- Since 1995, OWI Zala Bt. has been operating as a subsidiary of the German OWI GmbH. & Co. KG. Their products are usually marketed in Europe, but through the mother company, they can sell to overseas market as well (OWI ZALA 2013).

- In 2004 the former Fibreboard Manufacturing Co. of Mohacs (MOFA) and KRONOSPAN Holding Limited formed KRONOSPAN-MOFA Hungary Fibreboard Manufacturing Co. (MOFA 2013).
- Szombathely based FALCO particle board plant, established in 1939 as a small-scale sawmill operation facility, joined KRONOSPAN Holding in 2007. Since then, it has turned out to be the largest furniture and structural panel manufacturer in Central-East Europe (FALCO 2013/a).

The primary goals of all modern manufacturing facilities are to use high technology and to optimize the price/quality ratio of their products. Beyond these, environmental protection is gaining significance too as customers increasingly prefer products manufactured by environment friendly technologies. There are several establishments like FSC<sup>2</sup>, CARB<sup>3</sup>, and PFC<sup>4</sup> that evaluate and certify the use of environmentally friendly technologies. The majority of Hungarian wood-based panel manufacturers fulfil the requirements of these environment protective regulations.

Due to constant competition, market success requires significant investment and technological development. Some Hungarian wood-based panel manufacturers won state and European Union grants although these required some self-financing as well. Derula LLC received financial support for doubling its forest area in 2001, and for doubling production capacity in 2013 (HVG 2011; Derula 2013). In 2013, the MOFA-Hungary LLC received financial support to switch from using the wet process to a more environmentally friendly dry fibreboard manufacturing technology. This increased production capacity and by-product utilization (MOFA 2013). A grant received by FALCO Zrt. in 2013 helped them develop innovative surface finishing technologies and contribute to quality and production improvements (FALCO 2013/b). At Furner-Pack LLC, the upgrade of production equipment was financed through a grant (Furner-Pack 2013).

There are two segments of the industry competing for the same wood raw materials, namely the wood-based panel and the bioenergy generating enterprises. Whether or not Hungarian forest management would be able to fulfil increased demand in the long term is questionable.

## 7 HUNGARIAN FOREST MANAGEMENT

As a consequence of the Trianon peace treaty at the end of World War I, Hungary became the least forested country in Europe with only 11.8% of its territory under forest cover. With significant efforts and investments in plantations, the percentage of forest cover reached 20.8% by 2014. Still, this is only 35% of the European average and compared to the forested areas of Central-European countries like Slovenia (62%) or even Poland (30%), it is a modest value. The long term strategy of Hungarian forest management is to attain 26–27% forest coverage for the country (FAO 2015; Barbu 2011; NÉBIH 2015).

An increase of forest cover yields an increase of current growth and an increase in usable growing stock. However, exploitation is limited to 62.7% of the total forested area designated for industrial utilization. The remaining areas are protected (36.2%) and recreational (1.1%) forests where harvesting for industrial purposes is not allowed (NÉBIH 2014). The volume of tree harvesting is about 70–75% of the current grow (*Figure 4*).

<sup>2</sup> FSC (Forest Stewardship Council) certifies the use of sustainable forestry operations by monitoring the responsible wood utilization until it reaches the end users.

<sup>3</sup> CARB (California Air Resources Board) certifies the conformance to air quality and contamination regulations.

<sup>4</sup> PEFC (Pan European Forest Certification Scheme) certifies that wood raw material originates from sustainable forestry.

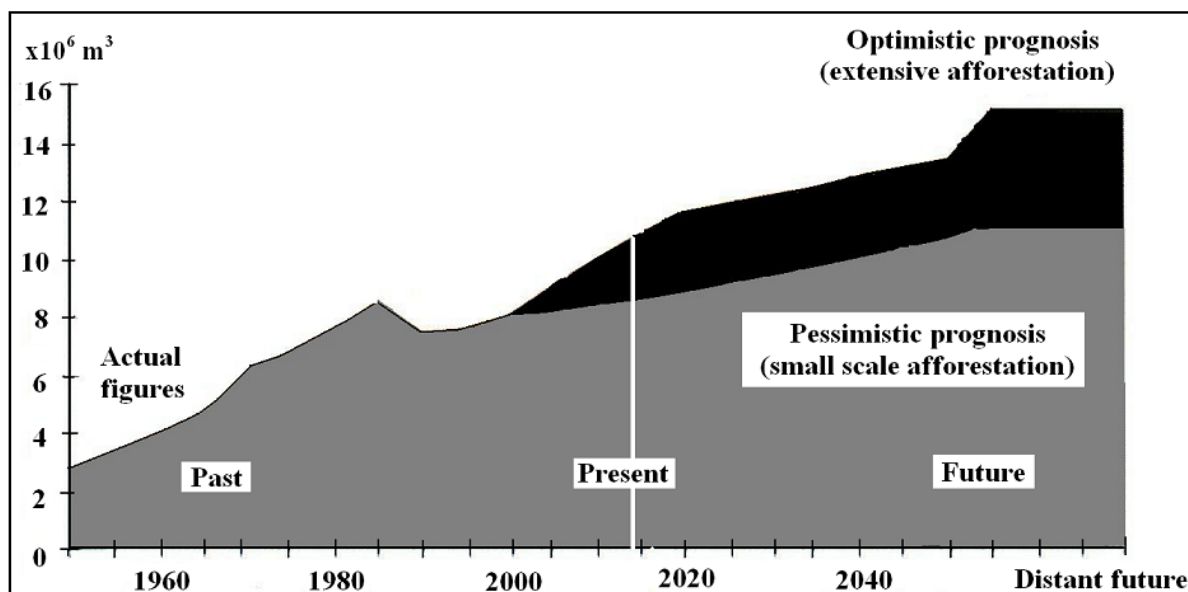


Figure 4. Prognosis of Hungarian timber yield (Source: ÁESZ 2002, p. 62)

Figure 4 shows the actual past, present, and the expected timber yield of the future. The prognosis includes two scenarios. It seems that extensive afforestation will be realized. This means that if the current trend continues, forest enterprises will produce sufficient volumes of wood to supply all domestic sectors of the wood processing industry.

The species composition of Hungarian forests is uniquely diverse (Figure 5). Angiosperms are dominant (88.9%) and only 11.1% of the total area are covered with conifers. Native hardwoods like oak, turkey-oak, beech and hornbeam comprise 63% of the forest. The remaining 37% is covered with introduced wood species such as black locust, red-oak, as well as some spruce and pine species. Consequently, this diversity in species determines the composition of split round-wood and fuel wood materials.

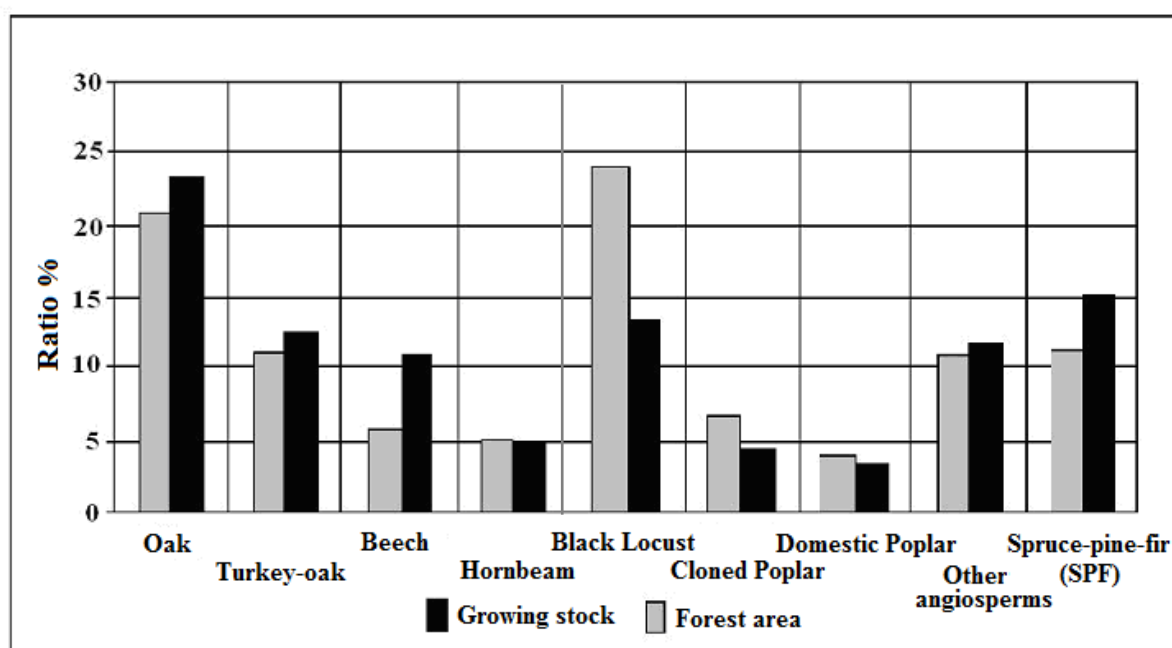


Figure 5. Species distribution of Hungarian forests and growing stock (Source: NÉBIH 2014)

It is worth considering afforestation or plantation forest management on land abandoned by agricultural cultivations because of unfavourable characteristics such as sloping, hard to approach locations, or game-damaged territories. These available areas may be as large as 650-700 kha (Molnár et al. 2008). Plantation trees show improved characteristics within species. For black locust and cloned poplar, the average height increase is about 20%, while in terms of the diameters, a 30% improvement was reported (Németh et al. 2004).

The ratio of domestic and cloned poplar species in the growing stock increased from 7.3% to 10% due to the long term investments of financially stable panel manufacturing companies like Derula LLC in Szolnok. However, the volume of growing stock of beech, which has a longer rotation period, reduced by 0.3% (NÉBIH databases 2010–2014. year). Beech is the most valued raw material of wood-based panel manufacturing. According to a report, the area of good quality beech forest might decrease further (Molnár 2004).

The suitability of two readily available species, the turkey-oak and black locust, for medium density fibreboard (MDF) manufacturing has already been researched. Experimental results indicated appropriateness (Winkler 1999). A poplar-black locust-oak-Scotch pine mixture was successfully tested for particleboard production (Winkler 1998). Unfortunately, none of the above mentioned research results reached commercialization. Wood processing wastes could be a supplementary raw material source of the wood-based panel industry. Wastes or residues generated by different wood processing technologies are usually incinerated to produce heat or electrical energy. Instead of burning wood wastes, the creation of value added products and elongated carbon retention are the key arguments for building these by-products into wood-based panels. All of the segments of the forest products industry generate wastes like sawdust, wood bark, etc. Outcomes of completed research works demonstrated the viability of such wastes for particleboard production. Despite these results, no industrial utilization has happened yet (Winkler 2005a).

Inorganic bonded wood composite panel manufacturing is another major sector of the wood-based panel industry. Several research results demonstrated that wastes produced by other segments of the wood processing industry and domestic hardwoods like black locust and turkey oak can be successfully converted into inorganically bounded panel products. For gypsum bonded fibreboard, the use of recycled flue-gas, gypsum and fibre-silt creates not only a good quality panel, but eliminates environmental hazards as well (Winkler 2005b).

Experiments with fibrous plastic wastes were conducted at the fibreboard manufacturing plant of Mohacs. Results showed that residues of packaging material processes can be transformed into structural panels (Winkler et al. 2005).

The volume of green trees increased continuously during the past years. By now, the growing stock is about 13.1 million gross m<sup>3</sup> annually (NÉBIH 2014). This increase is partially due to sustainable harvesting, afforestation practices, and the conversion of forest structures. Additionally, less demand for woody raw materials resulted in less extraction than allowed by the annual felling target.

The primary purpose of energy-forests is to provide fuel for biomass operated power-plants. However, such special forests may also contribute to the raw material supply for wood-based panel manufacture if appropriate technology is used for the conversions.

The composition of the 2338.3 ha of recently planted energy-forests has three dominant species. Namely, they are willow, black locust and poplar species (*Figure 6*).

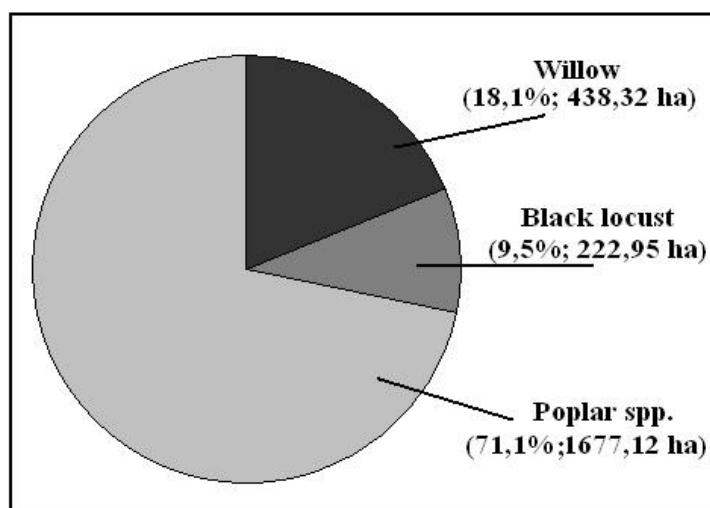


Figure 6. – Species composition of planted Hungarian energy-forests.  
(Source: NEBIH 2013)

Table 3. The use of wood-based biomass in Hungary

| Application type                           | Domestic raw materials                                                                  | Imported raw materials                                           |
|--------------------------------------------|-----------------------------------------------------------------------------------------|------------------------------------------------------------------|
| Direct use for energy production           | 3.5 Million m <sup>3</sup> firewood<br>5,000 tons pellets<br>2,000 tons wood briquettes | 78,000 m <sup>3</sup> firewood<br>15,000 tons and other archives |
| Indirect use for energy production (waste) | 65,000 m <sup>3</sup> wood waste for energy purposes                                    | 240,000 tons wood waste for energy purposes                      |
| Short rotation energy plantation           | 3,398 m <sup>3</sup> (poplar and willow)                                                | –                                                                |
| All energy                                 | 656.3 ktoe                                                                              | 89.5 ktoe                                                        |

(Source: NEBIH 2014)

The use of wood-based biomass is based not only on domestic available supplies, but also on additional imported sources (Table 3). The latter could be reduced or even completely replaced by further afforestation, which could affect major cost savings.

Further possibilities to increase the area of plantation forests are:

- Drained flood-plains and flood-prone areas are excellent growing sites for near-to-nature plantation forests.
- By controlling water supply on former flood-plains, the non-native species may result in plantations having different growing cycles.
- Planting drought resistant (xeromorphic) non-native species on arid growing sites may increase dendromass production.

The major advantage of plantation forests is that fast growing, non-native species can be cultivated. This provides quick return of investments for the owners and lessens the extractions from the primary forests. However, there is a hazard that non-native species become invasive and may transmit dangerous infections to which the indigenous trees are not immune (OEE 2012).

The major financial basis of forest management and forest conservation is the revenue generated by forest sales (Gémesi 2005). Only 60% of the volume allowed by the harvesting plans is realized as gross logging. From this about 1.5–3% are high quality veneer logs that are the raw materials for veneer-based wood panels and decorative veneers (Németh – Szabadhegyi 2003).

Besides wastes/residues of the forest products industry, the raw materials of particleboard, fibreboard, cellulose and paper manufacture are stacked and split round woods. These comprise 20% of the total volume of harvest, while the fuel wood share is 50% (NÉBIH 2010–2015). These two forest materials gained importance because of the widespread use of wood as fuel for energy generation. However, split round wood use for wood-based panel manufacturing generates significantly higher revenue than can be achieved by burning (Fekete 2004).

The volume of industrial use saw logs is about 15–18% of the total harvest. The highest quality saw logs are usually exported though. The price and utilization of the domestically available stock may be affected by foreign policies of forest management. This indirectly harms the local wood-based panel industry. For instance, in Poland the profitability of the forest products industry and workplaces are endangered because German entrepreneurs buy out Polish forest lands near the border. They pay a higher price than the local market value because in Germany the exploitation of forests had been limited (Barabás 2013). It is expected that in Romania the significant volume of log and timber products export will be limited to protect the raw material supply of the local forest products industry (Balogh 2013; Barbu 2013). These phenomena can manifest in Hungary too and may influence the wood supply and the current situation of the wood processing industry.

## 8 FUTURE OF THE WOOD-BASED PANEL INDUSTRY

Reviewing the raw material supply, as well as the technological and ownership situations of the wood-based panel industry, several trends may be recognized. The interactions between these deterministic factors can influence the future of this segment of the forest products industry. Some facts regarding the existing or expected circumstances may be as follows:

- The quantity of available wood raw material is continuously increasing due to sustainable forest operations. By the expansion of plantations and private forests, a significant volume of good quality industrial wood may ensure the raw material supply of the panel industry.
- The major manufacturing facilities were acquired by foreign companies. The locally produced raw material decreases transportation cost, increases profitability and may motivate the owners to further invest in technology development for which EU and state grants may be available.
- Belonging to large foreign enterprises has a definite advantage. Domestic products can reach an extensive foreign market via the mother company.
- The wood-based panel industry already operates in an environmentally conscious manner. The significance of this segment of the forest products industry may increase in the future. However, its raw material demand is certainly competing with the needs of biomass utilizing power-plants. Plantation of short rotation trees on private and energy forests is one of the solutions for this problem.
- There is a great potential to supplement the raw material source by recycling wood, though it requires a well-developed collection, storage, and redistribution network.
- Finally, the export of wood resources may harm the supply of the domestic wood-based panel manufacturers, thus it should be limited to a certain extent.

## 9 SUMMARY

Nowadays environmental protection plays as important a role in industrial activities as profitability does. The irreversible destruction of the natural environment, including

deforestations, have a catastrophic effect on nature and on the well-being of human life. The forests and the comprising wood species produce oxygen, the basis of life, and absorb CO<sub>2</sub> gas, which is a major contributor to the greenhouse effect. The most harmful load on the environment is generated by energy production. In an effort to decrease CO<sub>2</sub> emissions, non-renewable energy sources the majority of these power plants use, like coal, crude oil and natural gas, need to be replaced by renewable, environmentally friendly fuel. The energy sources of biomass power-plants come from forest operations and agricultural production. It includes short bolts, split round-wood, pulpwood, bark and by-products of sawmilling. These materials are raw materials for the wood-based panel industry. The delayed release of CO<sub>2</sub> in woody materials requires the long-term use of wood products containing stored carbon. Traditionally, the wood-based panel industry of Hungary is one of the most effective segments of the forest products industry in the utilization of low quality wood resources. Its products, manufactured in an environmentally conscious manner, satisfy the international regulations of clean production processes and quality. The raw material demand of the wood-based panel industry could be satisfied with the current afforestation practice in the country. New special energy-plantations not only provide extra wood resources, but the wastes and other non-usable parts of trees contribute to the profitable operation of biomass utilizing power-plants.

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## Guide for Authors

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## Contents and Abstracts of the Bulletin of Forest Science

Bulletin of Forest Science (Erdészettudományi Közlemények) is a new journal supported by the Hungarian Forest Research Institute and by the Faculty of Forestry of the University of West Hungary. The papers are in Hungarian, with English summaries. The recent issue (Vol. 6, 2016) contains the following papers (with page numbers). The full papers can be found and downloaded in *pdf* format from the journal's webpage ([www.erdtudkoz.hu](http://www.erdtudkoz.hu)).

### Vol. 6, Nr. 1, 2016

Csaba MÁTYÁS and Koen KRAMER:

#### **Adaptive management of forests and their genetic resources in the face of climate change...7–16**

**Abstract** – The consequences of the projected climatic changes on the health and growth of European forests are for the time being still unresolved and debated. Analysis of provenance tests and dynamic modeling of four European tree species indicate that the impacts are regionally different. In the temperate-maritime zone, expected rise of temperature – in case of sufficient precipitation – may lead to growth acceleration without significant genetic change. In the southern continental and Mediterranean zone, at the lower (xeric) limits of distribution, however, summer drought increase will trigger higher susceptibility to diseases and mortality, and may cause local extinctions and shifts of distribution area. Extreme selection may narrow genetic variation and cause decline of stability, key attributes to withstand environmental changes. Results confirm that the prudent use of regional differentiation in genetic diversity and stability may provide possibilities for alleviating climate change risks and increase the fitness of next generations. The presented policy principles of adaptive management are based on results of the FORGER project, and were published as Policy Brief (Mátyás and Kramer 2016).

Gábor ILLÉS, Tamás FONYÓ, László PÁSZTOR, Zsófia BAKACSI, Annamária LABORCZI,  
Gábor SZATMÁRI and József SZABÓ

#### **Results of Agroclimate 2 project: Compilation of digital soil-type map of Hungary...17–24**

**Abstract** – According to the tasks of Agroclimate 2 project it was necessary to compile from forestry and agriculture viewpoint an equally applicable soil and landsite database with countrywide coverage. To achieve this by the unification of present forestry and agricultural landsite databases and by using a set of meaningful environmental predictor variables under the umbrella of digital soil mapping approach we started to compile digital soil maps. Our efforts resulted in the first version of Hungary's new digital soil map, which provides information on soils with a spatial resolution of 1 ha. On the basis of the validation of the map

we concluded that its confidence is approximately 70%. By the exploitation of refining possibilities provided by the digital soil mapping methods further efforts will be made to achieve prediction accuracy above 80%.

Gábor ILLÉS and Tamás FONYÓ

**Assessing the expected impact of climate change on forest yield potential in the AGRAGIS project...25–34**

**Abstract** – Climate change requires actions from political, social, economic, and scientific stakeholders. The AGRAGIS project during the development of National Adaptation Geo-information System aimed to assess the climate change induced potential impacts on yield conditions of forests. During the project on the basis of the historical meteorological database of the country (CarpatClim-Hu), and using the ALADIN and RegCM regional climate models we have assessed the expected forest climate zone shifts in Hungary. Yield data of forests as a baseline came from forest stands that were established in the early 1960s, which are being now the 6<sup>th</sup> age-class. Yield data for forests under changed conditions came from forest stands that were established in the early 1990s, which are being now the 3<sup>rd</sup> age-class. Climate change facts between the periods of 1961-1990 and 1991-2010 can be statistically evaluated in this way together with yield changes of forest stands. By the projection of average statistical differences according to site we can assess the expected changes in yield potential for future time windows of 2021-2050 and 2071-2100. Results showed that a drop is expected for all major species' yield potential to different extent under future climate conditions.

Balázs GARAMSZEGI and Zoltán KERN

**Basal area growth trends of Hungarian beech forests in a changing climate...35–44**

**Abstract** – Multidecadal trends of mean basal area increments of beech from three sites and four different stand ages were investigated in Western and Northern Hungary. Regardless location and age, our findings show a slowdown in growth or even significant increment decrease for the past 30-40 years. Although the phenomenon is connected to unfavorable changes of climatic conditions, no clear linear relationship can be detected between the decadal trends of increments and the widely used forest aridity indices.

Gergely JANIK, Anikó HIRKA, András KOLTAY, János JUHÁSZ and György CSÓKA

**50 years biotic damage in the Hungarian beech forests...45–60**

**Abstract** – We examined the database of the Forest Research Institute derived from the reports of the forest-managers. We indicated the important pest and pathogen damage areas from the last 50 years. We also compared the data to drought-indexes. The frequency and severity of damages increased from the mid-1980's. The beech-decline occurred on larger areas, if the values of the drought indexes were above certain values in the predecesing 2 years.

Ernő FÜHRER, Márton EDELÉNYI, Anikó JAGODICS, László JEREB, László HORVÁTH, Zoltán KERN, Andrea MÓRING, Ildikó SZABADOS and Zoltán PÖDÖR

**Effect of weather conditions on the annual basal area increment of a beech stand of old age...61–78**

**Abstract** – We studied the effect of meteorological parameters on the basal area increment (BAI) of a beech stand in the Sopron Mountains between 1985 and 2007. We evaluated the meteorological conditions of the area by using breakpoint-analysis, and the results showed

rising temperature and decreasing rainfall in certain months of the vegetation period. Regarding to the trends of BAI, we observed a significant decrease in the main growth period (May–August) and a significant increase in the final growth period (September–October), while the annual tree growth showed a strong significant decreasing trend. Multivariate regression analysis was used to determine the relationships between the BAI and the climatic variables in the given and also in the previous two years. We found that the previous year's precipitation has positive, while autumn temperature has negative effect on the BAI. At the same time current spring to early summer precipitation enhances the beech growth, and in contrary, the mean temperature in June and July has negative effect on the BAI. Based on the results, we can conclude that according to the forecasted changes in climate, not only further loss in growth but also drastic decay in vitality and tolerance can be expected for beech at this site in the future.

Éva KONKOLY-GYURÓ and Pál BALÁZS

**Forest cover change in the Carpathian Basin from the mid 19<sup>th</sup> century till nowadays...79–97**

**Abstract** – Human impact on landscape might be followed by the assessment of land use and land cover change. In the project „200 Years of Land Use and Land Cover Changes and their Driving Forces in the Carpathian Basin in Central Europe” founded by the NASA Land-Cover/Land-Use Change Science Program, a GIS dataset on the historic land cover, of a nearly 350.000 km<sup>2</sup> area has been provided. Four time layers, based on historic maps and CLC data have been assessed by GIS and statistical methods. The focus of the present paper is the forest cover change amongst the results of the land cover transformation processes. The main tendencies of changes of the entire study area and the specificities of the main landscape types are being presented here.

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Gábor ÓNODI

**Habitat transforming effects of non-native and invasive tree species...101–113**

**Abstract** – The spread and habitat transformation effects of invasive plant species cause global environmental problems. In Hungary occurring invasive tree species, such as black cherry, common hackberry, russian olive, black locust, tree of heaven, boxelder and green ash, can transform native communities and architecture of habitats considerably. These species have usually less consumer species comparing to native tree species. Their pests can be introduced with them as well, which can also become invasive. Tree rot fungi can colonize them slower, so that less diverse microhabitats would form on them, and so less species would inhabit them. Habitat transformation can be facilitated by antropogen influences further, such as soil works, deforestation and river control. Climate change can influence the range and occurrence patterns of both native and alien species. Alteration of native communities could be so intensive, that habitat restoration would be much source and work intensive, even if it would be possible.

Ádám SILNICKI, Gergely ZAGYVAI and Dénes BARTHA

**Comparative surveys on vegetative organs of hungarian ash (*Fraxinus angustifolia* Vahl subsp. *danubialis* Pouzar) and common ash (*Fraxinus excelsior* L.)...115–125**

**Abstract** – The aim of present study was to discover the morphological variety of vegetative organs of two native *Fraxinus* species (*F. excelsior*, *F. angustifolia* ssp. *danubialis*) and to separate different taxa and hybrids through their vegetative morphological characteristics. Studied populations were originated from Rábaköz – Répce-plain area, Sopron-Hills and Gemenc. During statistical analysis multivariate statistical methods were applied such as Principal Component Analysis (PCA) and Principal Coordinates Analysis (PCoA) to demonstrate the correspondences between morphological characteristics and specimens. As a result of statistical analyses *F. excelsior* specimens separated significantly from the sample group consisted of specimens identified *F. angustifolia* ssp. *danubialis* and hybrids. Most of measured morphological variables proved to be highly distinctive in the case of above mentioned two sample groups, if they were applied collectively. Strongest distinctive features between *F. excelsior* and mixed group were the width variables of leaflets and leaflet teeth density, although these variables proved to be unsuitable for separation of hybrids.

Dénes MOLNÁR, Iván BARTON, Kornél CZIMBER, Tamás BAZSÓ and Norbert FRANK

**Investigations on stand structure in the Roth memorial forest...127–136**

**Abstract** – During transformation of even-aged forests to selection forests it is important to follow the changes in stand structure. Detailed forest mapping was made in Sopron 182 B experimental selection forest, where the research was started by Roth Gyula in 1936. The main purpose of the survey was to create a database which can be used for timeline analysis in the future. We developed a survey method which is accurate enough to generate spatial forest stand databases. We made a 3D model of the forest and examined its structure. During the decades of the experiment beech became dominant, light-demanding tree species withdrew to upper canopy regions. Diameter and height distribution is heterogeneous, in some areas it shows the characteristic of selection or structurally differentiated forests.

Tivadar BALTAZÁR, Ildikó VARGA and Miloš PEJCHAL

**Distribution of European mistletoe (*Viscum album* L.) according to the location of host species in the castle park of Lednice, Czech Republic...137–150**

**Abstract** – The aim of this study was to examine the distribution of European mistletoe (*Viscum album*) in the castle park Lednice, Czech Republic studying the dependence of the infection intensity and location of host species. From the most common host species (23) more than 1600 infected individuals were involved in the analysis. Based on our results it can be concluded that the host species are infected differently, since some hosts (e.g. *Acer saccharinum*, *Acer sacharum*, *Juglans nigra*) are more sensitive to the presence of mistletoe and these woody species are much heavily infected. Our results also show that the relationship between the tree location and the intensity of mistletoe infection is statistically significant. It means that solitary trees are most heavily contaminated with mistletoe. Furthermore, those individuals are less endangered, which are situated in closed canopy groups. Nevertheless, the ratio of uninfected and infected individuals are almost the same in case of solitary trees or in different canopy groups too.

Bálint HORVÁTH

**Zoogeographical characteristics of the nocturnal macrolepidoptera fauna of sessile oak-hornbeam forests in the Sopron Mountains...151–159**

**Abstract** – The Lepidoptera fauna of the Sopron Mountains is well known; more than 800 species was published. The oak forests have high importance in the region, because they support a high species richness of Lepidoptera. Macromoths which occur in sessile oak-hornbeam forests in the study area are classified in five larger faunal types. The most important are the Trans-Palearctic, West-Palearctic and “Siberian” species from which the Euro-Siberian, Holomediterranean and Boreo-Continental faunal types compose the basic fauna. Moreover, several further faunal elements are known from the Sopron Mountains, such as South Continental and Extra-Palearctic species, furthermore other Mediterranean and Boreal components.

Ferenc JÁNOSKA, Péter KEMENSZKY, Attila FARKAS, József VARJU and Zsolt HORVÁTH

**Artificial nest predation investigations at a varied habitat in Somogy County, Hungary...161–173**

**Abstract** – We made artificial ground nest predation investigations at a varied habitat in Somogy County, Hungary. During the investigation we were interested in determining which predator species pose a potential risk for the nests of small game species (pheasant and grey partridge) in a territory, where the habitats are suitable for both small game and big game. We monitored 20-20 artificial ground nests in April and May. In each nest we put 2 chicken eggs, 1 wax egg and 1 plasticine egg, respectively. We placed the artificial nests at the edge zones of different habitats and checked the predation every 4 days. We found the Red Fox (*Vulpes vulpes*) (51%) and the Wild Boar (*Sus scrofa*) (37%) to be the most common predator species. We found in April the highest predation at the edges between the Alder forests and crop fields and the Alder forests and pastures and in May at inner micro edges of young afforestation, the differences were significant. The predation risk was also very high for artificial nests left at inner micro edges of young afforestation for 2 months, but the differences between the study periods were not significant.

Dániel HÁMORI

**Conservation biological aspects of the little owl (*Athene noctua*, Scopoli, 1769) adapted to anthropogenic nesting environment, Upper-Kiskunság, Hungary ...175–187**

**Abstract** – The Little Owl (*Athene noctua*) is a strictly protected species that avoids closed forests. The species originally nested in cavities in the trunk and branches of decaying trees. These natural nesting sites have become extremely scarce so the species have switched to an anthropogenic nesting environment where potential nesting hazards associated with the presence of beech martens (*Martes foina*) (74 %), with electrocution risk by uninsulated medium-voltage power-lines (51 %) and with danger of poisoning by rodenticides (32 %) may occur. During the period covered by the present study (2003-2015) nearly 400 artificial Little Owl nest boxes were installed in the Upper-Kiskunság region and a total of 467 birds (adult and pullus) were ringed. It can be safely assumed that the growing nest box occupancy rate in recent years indicates a rise in population. By 2015, nest box occupation rate had risen to 25,4 %. The present study, besides outlining the conservation solution of artificial nest boxes in the short term, proposes a suggestion for a long-term solution based on international practice by restoring the natural nesting environment for Little Owls.

Zoltán VARGA and Attila FARKAS

**Examination of food of badgers (*Meles meles* L.) in Komárom-Esztergom county, Hungary...189–197**

**Abstract** – In the 2009/2010 hunting season 77 badgers were collected in the territory of Komárom-Esztergom county. Some of the animals were legally hunted specimens, but the 41.5% of sample resulted by road accidents. On the samples, analysis of dietary habits was performed, which was accomplished by analysis of stomach contents. The results were evaluated separately according to habitat types and seasons, based on location and time of the killing, or inventing. We examined the relative frequency of occurrence and diversity of food items in stomach contents, as well as trophic niche breadth and standardized trophic niche breadth of badgers. We intended to reveal the occurrence of small game species in badger's diet and differences in feeding habits between the various habitats and seasons. The studies have shown that feeding habits of badgers living in different habitats and collected in different seasons differ significantly based on consumption frequency of certain food categories. However, the presence of small game species in the diet of badgers has not been proved. We found that on the test area badgers are feeding generalist species, with periodic specialist features characteristic only in certain habitats.



